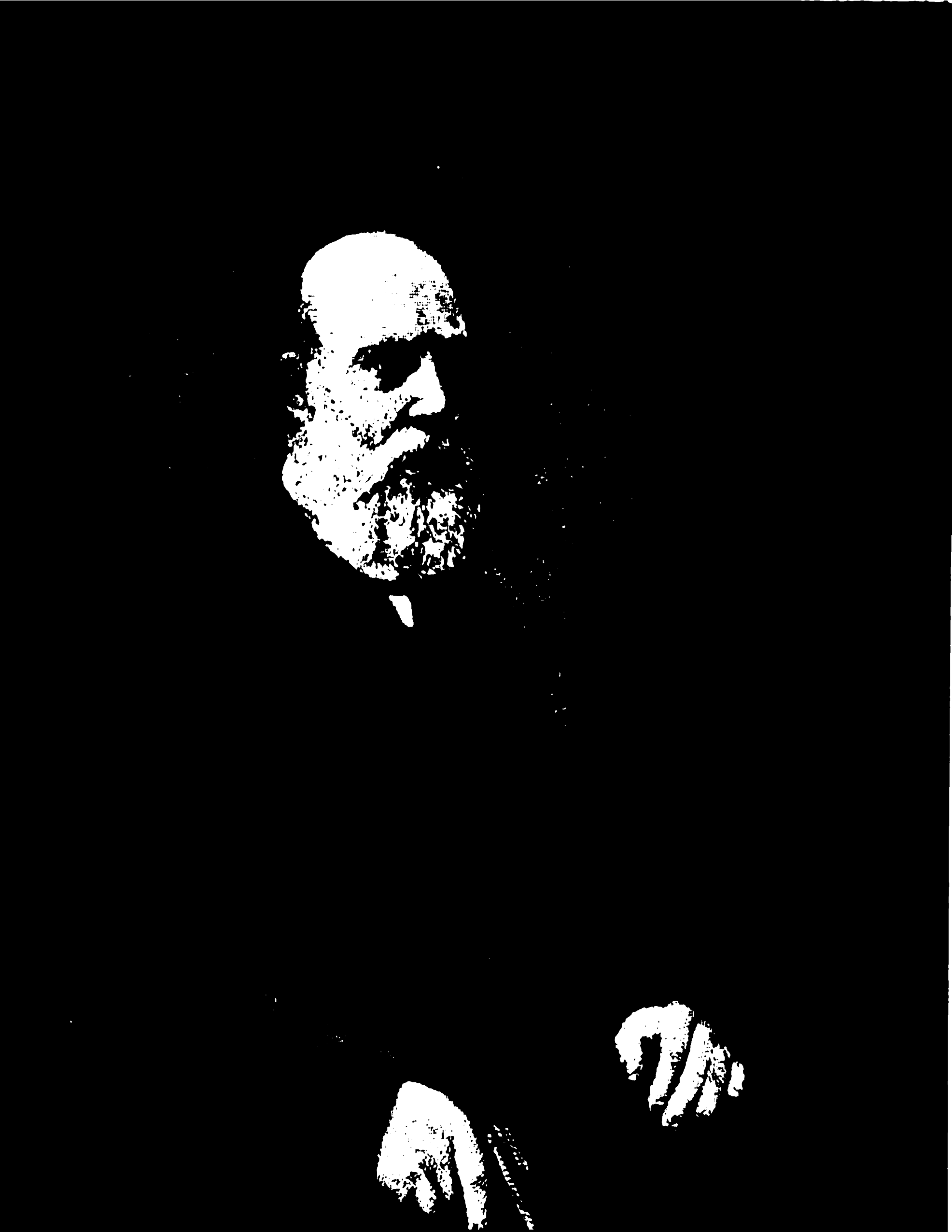

Minutes of proceedings of the Institution of Civil Engineers

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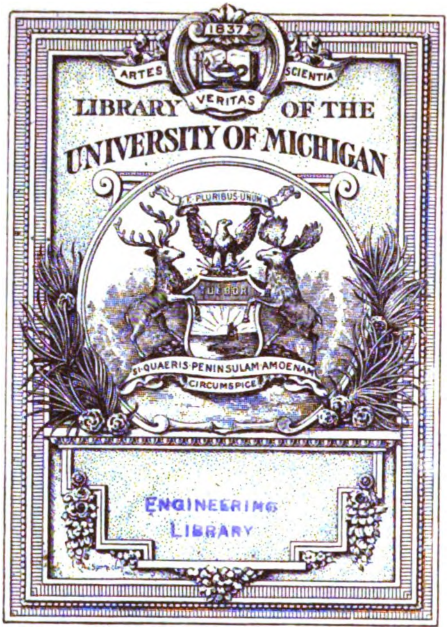
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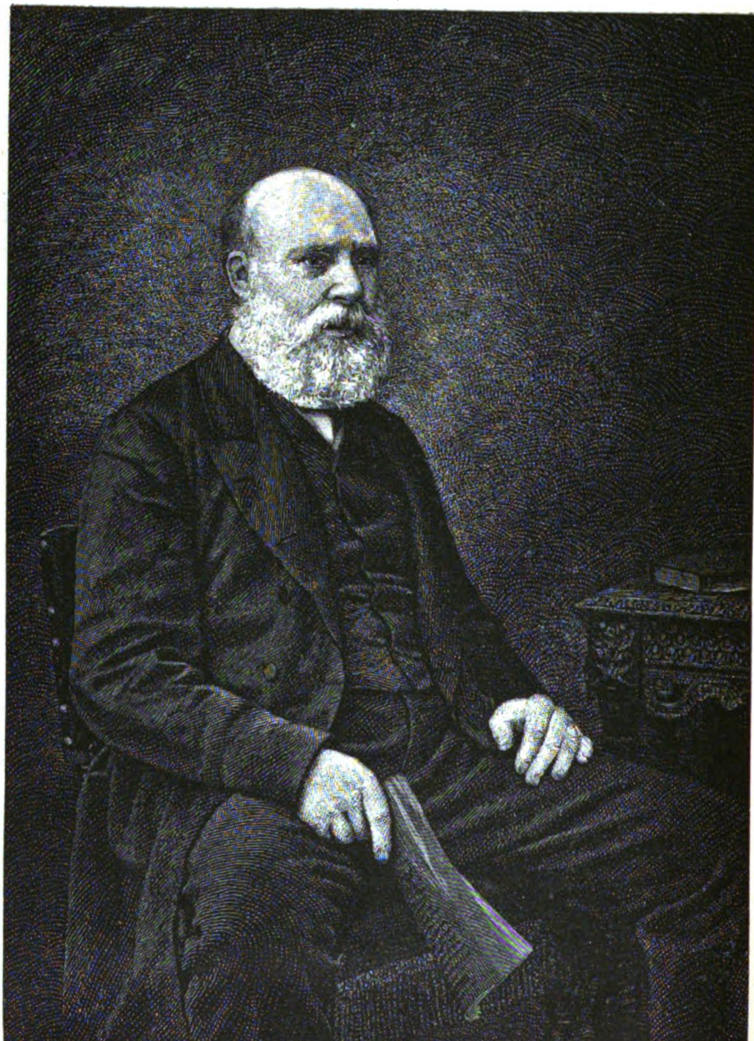

See Obituary Notices.

CHARLES MANBY, F.R.S., M. INST. C.E.

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXXI.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. lxxx., p. 268, in the numerator of the formula at the head of the page, *for* "π" *read* "n." The result "T" is in French Horse-power.

" " Plate 6, Fig. 1, *for* "r" *read* "h," *for* "e"—representing weight—*read* "l," and *for* "e^1" and "e^2"—representing safety links—*read* "l^1" "l^2."

" " " Fig. 2, *for* "*enlarged detail of friction-wire*" *read* "*enlarged detail of Frictional Skate B.*"

" " p. 347, line 5, *for* "28th" of August *read* "12th" of August.

" lxxxi. Mr. Tomlinson's remarks, p. 52, are illustrated by Plate 4A.

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1884–85.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

17 February, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2054.*)

"The Metropolitan and Metropolitan District Railways."

By BENJAMIN BAKER, M. Inst. C.E.

IT may not unreasonably appear to many that a Paper on a railway, a portion of which was opened for public traffic nearly a quarter of a century ago, must necessarily be of little present interest to members of the Institution. The Secretary has thought otherwise, however, and it is in response to his application that the present Paper has been prepared by the Author, with the cordial acquiescence of his partner, Mr. Fowler, Past-President, the originator of the present system of underground railways. If any further apology is needed for the Paper not having been written before, it must be found in the fact that the complete scheme for the "Inner Circle" of railways recommended by the Select Committee of the House of Lords in 1863, although projected long since, has only just been accomplished.

In treating on so comprehensive a subject as the general history and detailed construction of the "Underground Railway," the Author must necessarily omit many things, and touch but lightly upon other questions, such as the system of working and ventilation, which would in themselves singly afford appropriate subjects for Papers. To preserve some sort of order in the mass of material to be dealt with, he proposes to give, first a brief account of the early history of the undertaking, its gradual development, and like matters not of a strictly engineering character, and then proceed to consider, in such detail as time will permit,

the engineering features of the railway, its gradients, tunnels, sewer-crossings, and other ordinary and special works of construction, confining his attention chiefly to the 11½ miles out of the whole 13 miles of "Inner Circle" with which he was himself personally connected.

Historical and General.

Parliamentary.—The first length of Metropolitan Railway constructed was that from Paddington to the City. Various claimants have contended for the honour of originating the scheme, but the Author is of opinion that it was rather a product of the growth of London than the work of any single individual. In the year 1814 Paddington was described as, "a village situated on the Edgware Road, about a mile from London." Twenty years later the advance had been such that the public were carried by steam-power between Paddington and Moorgate Street, at the same fares as at present, but in carriages running along the surface of the Marylebone Road, instead of beneath it. Another twenty years' interval, and the year 1854 is the date of the Act of Parliament for the "North Metropolitan Railway: Paddington to the Post Office, Extensions to Paddington and the Great Western Railway, the General Post Office, the London and North-Western Railway, and the Great Northern Railway. John Fowler, Engineer; John Hargrave Stevens, Architect." Thirty years then elapsed before the entire "Inner Circle" of Metropolitan railways was completed and opened for public traffic, the dates of opening the different lengths being: Paddington to Farringdon Street, January 1863; Extension to Moorgate, December 1865; to Westminster, December 1868; to Mansion House, July 1871; to Bishopsgate, July 1875; to Aldgate, November 1876; to the Tower, September 1882; and the complete circle, October 1884.

In 1834 the steam-carriages then running were each capable of conveying about a dozen passengers from Paddington to Moorgate in thirty-five minutes, with a consumption of coke averaging from 10 lbs. to 12 lbs. per mile. In 1865 each Metropolitan train could carry between the same termini thirty to forty times the number of passengers, half as fast again, with a consumption of fuel only three times greater. Since the steam-carriages were introduced as an improvement upon the then existent omnibus service, no further evidence is required of the necessity of a Metropolitan railway of the type designed by Mr. Fowler.

About the eventful year 1845, railway companies began to realize the important commercial fact that it was necessary for

their stations to be as close as possible to the sources of traffic. No less than nineteen Bills were deposited that Session for lines within the Metropolitan area, and Parliament becoming alarmed, a Royal Commission was appointed to inquire into the matter. Mr. Vignoles, Past-President, had a scheme for a Charing Cross to Cannon Street line; Messrs. Stephenson and Bidder, Past-Presidents, one for an extension of the South-Eastern Railway to Waterloo Bridge; Mr. Locke, Past-President, for an extension of the South-Western Railway to London Bridge; and Mr. Page, M. Inst. C.E., for a line from the Great Western Railway through Kensington to Westminster, and along a proposed Thames Embankment to Eastcheap and Blackwall. There was also a North London Railway; a Regent's-Canal Railway; and Mr. Charles Pearson, the City Solicitor, whose name was honourably associated with the Metropolitan Railway in its early days, again set forth his pet project for a Grand Central terminus at Farringdon Street, and a connecting line from King's Cross. Quoting from the Report of the Commissioners: "Mr. Pearson would carry the line of railway between two rows of houses, which he proposes to build so as to form a spacious and handsome street, 80 feet in width and 8,506 feet in length. The railway to be on the basement level, and to be arched over so as to support the pavement of the street, which would be on the level of the ground-floor of the houses. Mr. Pearson proposes to give light and air to the railway by openings in the carriage-way and footpath." Although this system of construction presents few points of resemblance to the Metropolitan Railway as carried out, Mr. Pearson is clearly entitled to the credit of being the originator of the whole tribe of "Arcade railways," and similar devices under different names which have from time to time been brought forward at home and abroad. The Author would further point out that the City Solicitor was also the first suggestor of the "blow-holes," which have so vexed his successors. The Royal Commissioners of 1846 were not very far-seeing. They were of opinion that there were strong reasons for discouraging the carrying of a railway across the river within the Metropolis, because an increase in the number of bridges would create a new obstruction to the navigation, and to appropriate any of the existing bridges to the purposes of a railway would be an inconvenience and injury to the public. They also thought that the advantages to the public of bringing railway-stations further into the city had been exaggerated, because they found on inquiry that the average distance travelled by passengers who arrived at Euston was 64 miles, and concluded that the saving of another

mile or two was of little importance. It was clear, therefore, that in 1846 the time was not ripe for the successful promotion of a Metropolitan system of railways. However, Mr. Pearson and his colleague, Mr. Stevens, architect and surveyor to the western division of the City, who had worked at the subject from the year 1837, were not to be discouraged, but kept the important question of Metropolitan communications before the public, by bringing forward a number of propositions of varying merits for a City Terminus line, and for arcades, vegetable and meat markets, Holborn Valley Viaducts, and other improvements in connection with railways. Finally in 1853, as an outcome of all this preliminary ventilation of the subject, an Act was obtained for a line 2¼ miles in length, from Edgware Road to Battle Bridge, King's Cross; Mr. Fowler being the engineer, Mr. Stevens the architect, and Mr. Burchell the solicitor.

Plans for extensions westward and eastward, to Paddington and the City respectively, were at once prepared; and whilst the 1853 line was wholly under the public road, and no buildings whatever were scheduled, the extensions were taken through private property in places, with a view to obtain more convenient stations and better ventilation. Early in 1854 the Directors were able to announce that the Great Western Railway Company considered it "so important to obtain access into the heart of the City, that they had undertaken to contribute £175,000 to the capital if Parliament should sanction the proposed line from Paddington Station to the Post Office." The contest before the Parliamentary Committee was severe, but successful. Mr. Fowler was supported by Messrs. Brunel, Hawkshaw, Scott Russell, Peacock, and Stevens, and was opposed by equally eminent witnesses. It is proverbially dangerous to prophesy before you know, and few will be surprised to learn that distinguished engineers speculating thirty years ago on the subject of the Metropolitan Railway, were occasionally somewhat wide of the mark.

What was at the time deemed an important feature of the railway of 1854 was that it accommodated the Post Office. Sir Rowland Hill, writing to the Chairman of the Company, said: "The Post-Master General thinks it necessary that such arrangements should be made as will admit of the intended railway being brought into the basement of the building, so that the bags when made up may be placed at once in the railway carriages," and it was accordingly stated in evidence by Mr. Stevens before the Parliamentary Committee that this would be done. The same witness ventured to predict that the trip from Paddington to the City would be accomplished in twelve minutes if the railway

were made, but unfortunately it takes double that time. Another witness spoke very light-heartedly on the subject of tunnelling under heavy buildings without disturbing the surface or cracking the structures, because the Brunels had succeeded in carrying a tunnel under the Thames. Driving a tunnel, however, in the neighbourhood of buildings is, as the Author will show hereafter, one of the most precarious parts of the operations of a City railway contractor.

Working.—The original intention being to work the Metropolitan Railway by "hot-water" locomotives, no special provisions were made for ventilation. It was admitted in cross-examination that the only ventilation along a considerable portion of the line would be by the staircases, and that the stations themselves would be absolutely in the dark, or rather, dependent upon gas for illumination. Mr. Fowler foresaw and told the Committee that the traffic on the Metropolitan Railway would be essentially of an omnibus character, whilst both the through passenger traffic from the main lines and the goods traffic would be of comparative little importance. Very light trains of three carriages, running at from five to ten minutes intervals, would, he thought, best meet the requirements, and it was assumed the trains would stop at every alternate station, and perform the journey from Paddington to the City in fifteen minutes. Details of this kind are essential in order to account for some of the features of the line as constructed. Although Mr. Fowler proposed to use a locomotive burning no fuel, but having simply a reservoir of hot water capable of being heated up again at the end of each journey, and a reservoir of cold water to condense the steam, still he maintained that the line could be worked by ordinary locomotives. Mr. Brunel supported this view in most emphatic language. Quoting from his evidence before the Committee of 1854: "I believe," said he, "it would be perfectly easy to work this line with an ordinary locomotive, without any peculiar artificial means of ventilation. I thought the impression had been exploded long since that railway tunnels require much ventilation. There was a Standing Order in former days in the House that required the Committee should report on the means of ventilation; but the common answer given by engineers now is that they do not provide any. We are obliged in the Box tunnel, and one or two other tunnels, to put a screen to prevent the draught." He thought nevertheless that Mr. Fowler's proposed hot-water locomotive was "a rational and sensible way of working the line; there was nothing particularly new in it, for any one, who had driven a locomotive, knew perfectly well that if you were

going only four or five miles, and had a good large boiler with plenty of steam and water, well heated up, you need not take a fire." Mr. Peacock would have even dispensed with the condenser: "I should certainly commence with using the steam in the way Mr. Fowler proposes, and exhaust it in the tunnel in the ordinary way." Mr. Scott Russell had often driven a steamboat when the fire was out, and also a locomotive. As to loss of heat by radiation, he had made an experiment, and found the loss of pressure in five hours was only 30 lbs. per square inch. To sum up briefly the evidence of the eminent experts supporting the first Metropolitan Railway Bill, perfect unanimity was exhibited in three points; firstly, that the hot-water locomotive was beyond all dispute the best way of working the line; secondly, that trains weighing 20 tons, inclusive of passengers, but without engine, were the heaviest that could be usefully employed; and thirdly, that the trip would take from twelve to fifteen minutes.

Events have proved it was just on these three points that every anticipation was mistaken:—the hot-water locomotive was not even tried; the trains necessary for accommodating the traffic weigh, exclusive of engine, about 120 tons instead of 20 tons, and the time is doubled. Bearing these facts in mind, it can hardly be a matter for surprise that some of the earlier constructed portions of the Metropolitan Railway required further ventilation, when worked with coal-burning locomotives weighing 45 tons, and dragging 120-ton trains after them.

Before adopting ordinary engines Mr. Fowler instituted experiments, and took the opinion of many experienced locomotive-engineers. The detailed design and construction of the first locomotive for the Metropolitan Railway was entrusted to Messrs. Stephenson and Co., of Newcastle, about the end of 1860. This engine had a small fire-box, and a large mass of fire-brick stowed away in a chamber in the barrel of the boiler; the idea being to work it as an ordinary locomotive with full blast in the open portions of the line, burning there an excess of fuel in order to convert the white-hot firebrick into a reservoir of heat for use in the tunnels. Close-fitting dampers were provided to prevent the discharge of gases from the incandescent coke, and an injection condenser with air-pump disposed of the steam. The engine had four coupled-wheels, 6 feet in diameter, a pair of leading wheels, and cylinders 15 inches in diameter by 24 inches length of stroke. There were 230 square feet of heating surface in the chamber for fire-brick; 259 square feet in one hundred and eighty-nine tubes, 2 inches in diameter by 2 feet 7 inches long; 83 square feet in the fire-box,

and the grate area was 13½ square feet. In working order the engine weighed 32 tons, and the tender with 1,400 gallons of water 14 tons. The cost was £4,518.

Referring to a report of the trial of this engine on the 10th of October, 1861, the Author finds the results were considered to be the reverse of satisfactory. Steam was got up to 120 lbs. in three hours, and the engine run as an ordinary locomotive 7½ miles down the Great Western line, the fire-bricks being at a clear white heat. On the return journey the dampers were closed, and the exhaust turned into the condenser. The vacuum at first was 7 lbs., but in twelve minutes the steam came out of the delivery pipe of the air-pump mixed with boiling water, and it was deemed prudent to turn the steam out of the condenser. During this time the pressure had fallen from 120 lbs. to 80 lbs., and the coke-fire and bricks had assumed almost a black appearance. Owing to a failure of the feed-pumps it was desired to drop the fire; but the mass of fire-brick still remained a source of danger.

Messrs. Stephenson, profiting by the experience with the first engine, submitted an amended design, in which the fire-brick was retained and the air-pump dispensed with, but fortunately nothing further was done in the way of fire-brick locomotives. Sir Daniel Gooch from the first took a great interest in the working of the Underground Railway, and on one occasion raised the steam in a large Great Western engine to a high pressure, dropped the fire and ran 9 miles along the line with the stored-up heat. His views were that hot water was better than fire-brick, that both the boiler and the grate-area should be large, and the dampers perfect, and above all that the engine should be as simple as possible. Sir Daniel was called upon to build an engine for Metropolitan traffic, and did so, the trial taking place in October 1862, exactly a year after that of the fire-brick engine. Referring to the report of the trial, at which Colonel Yolland and the President of the Board of Trade were present, it appears that the engine did the trip from Farringdon Street to Paddington in twenty minutes, the weight of engine being 38 tons and of train 36 tons. The condensing water got hot, the sulphurous fumes came out of the ash-pan and fire-box door and a steam-jet had to be turned on to keep up steam, so the engine was not an unqualified success. As this was the first type of engine used for working the Metropolitan Railway traffic, it may be interesting to mention that it was a six-wheel broad-gauge tank engine, having four coupled wheels 6 feet in diameter, and outside cylinders 16 inches by 24 inches. The heating surface of tubes was 615 square feet, of fire-box 125 square feet, and the

grate-area was 18·5 square feet. A tank of 375 gallons capacity and a condenser of 420 gallons were provided.

For some months after the line from Paddington to Farringdon Street was opened, the Great Western Railway Company worked it on the broad gauge. Owing to a dispute as to terms the working of the line had to be carried on for a time with the assistance of the Great Northern Railway Company, and the engines used were six-wheel tender-engines having four coupled wheels 5 feet 4 inches in diameter, cylinders 15½ inches by 22 inches, and a total heating surface of from 760 to 940 square feet. Experience showed that both the Great Western and the Great Northern engines were too light for their work, and the powerful tank-engines now used on the line were designed by Mr. Fowler and Messrs. Beyer and Peacock. These engines have four coupled wheels 5 feet 9 inches in diameter, a four-wheel bogie and cylinders 17 inches in diameter by 24 inches length of stroke. The heating-surface of the fire-box is 103 square feet, of the tubes 909 square feet, and the grate-area is 19 square feet. The weight in working order is between 42 and 43 tons, with 1,000 gallons of water in the tanks.

Immediately the line was opened and the regular service of trains commenced, the theories of those who had stated in 1854 that the line could be worked by ordinary locomotives, were put to the test. It was found that even with the specially designed condensing engines of the Great Western Railway, the inconvenience from the discharge of carbonic acid and carbonic oxide gases was great. Alarmist paragraphs headed "Choke-damp on the Underground Railway" appeared in the daily papers, and with a view chiefly to allay panic a small fan and engine were arranged to blow air into the Portland Road Station. The glass was removed at once from the side lights at Gower Street Station, and three years later it was removed at Baker Street Station. Owing to the increased traffic and the use of coal instead of coke, there was another outcry in 1867, and the ventilation was further improved by opening portions of the covered way at King's Cross Station, Gower Street, Baker Street, Edgware Road, and Praed Street. Finally in 1871–2 the "blow-holes" were made between Edgware Road and King's Cross. Having this experience of inadequate ventilation on the first length of Metropolitan Railway, Mr. Fowler, in laying out the subsequent extensions and the District Railway, arranged wherever possible for the stations to be in the open with a piece of cutting at each end, and an intermediate cutting somewhere between the stations.

Extensions.—For some years after the passing of the Act of 1854, the public declined to assent to the practicability or usefulness of the proposed railway. The patience and perseverance of the promoters, however, ultimately prevailed, and in 1859, with the assistance of the Corporation of London, the capital was raised, the contract made, and the works commenced in March 1860. When opened, the success of the railway exceeded every anticipation, and numerous extensions were projected. It would be useless to enumerate the different projects brought forward or even the titles of the many Acts obtained. Suffice it to say that in 1861 powers were obtained for extending the Metropolitan Railway to Moorgate Street, and for widening the line from King's Cross eastward; and in 1864 for constructing the eastern and western extensions to Tower Hill and Brompton respectively, the District Railway from Brompton to Tower Hill, and the St. John's Wood Railway. Owing to financial difficulties the Metropolitan Railway Company sought to abandon the eastern extension in 1870, but the Bill was thrown out by the Lords. An alternative mode of completing the "Inner Circle," by Fenchurch Street instead of by Tower Hill, was authorized in 1871, but the latter and original route is the one adopted. As regards the western extension, Mr. Fowler's first idea was to take it through Kensington Gardens and Hyde Park, but the authorities objected, and the present line was selected. Practically there was little choice in laying out the extensions of the Metropolitan Railway, for the Lord's Committee of 1863 decided that "it would be desirable to complete an inner circuit of railway that should abut upon, if it did not actually join, nearly all the principal railway termini in the Metropolis, commencing with the extension in an easterly and southerly direction of the Metropolitan Railway, from Finsbury Circus at the one end, and in a westerly and southerly direction from Paddington at the other, and connecting the extremities of those lines by a line on the north side of the Thames." The inner circle of railways as constructed is the direct outcome of that recommendation. The total length of the line is 13 miles 8 chains, of which about 2 miles are laid with four lines of rails, and there are twenty-seven stations.

Cost and Traffic.—A statement of the cost of the different parts of the railway would be misleading as an indication of the relative extent of the works, because the financial liabilities assumed by the contractors varied from time to time, and other complicating conditions entered into the question. Referring to the original accounts, the Author finds that the contracts for the line from

Paddington to Farringdon Street were made with Messrs. Smith and Knight and Mr. Jay in January 1860, and the amount paid to those firms in final settlement was £674,751, which is equivalent to £186,000 per mile. Mr. Kelk next contracted for extending the line to Finsbury Circus, widening the line between King's Cross and Farringdon Street, enlarging Moorgate Street, building the repairing-shops at Edgware Road, and doing sundry other works, the gross cost of which was £779,376. Excluding special items, the Author estimates this to correspond to a cost of £208,000 per mile of double-line railway. Next in succession were the contracts with Messrs. Peto, Kelk, Waring, and Lucas for the completion of the Inner Circle, the gross contract sum being £2,743,000 for works and special financial liabilities. This contract was not carried out in its entirety, as the eastern end of the Inner Circle was temporarily abandoned, and the District Railway terminated at Mansion House Station.

It need hardly be said that the cost of property varied widely at different parts of the line, as did other charges, and it is difficult to give a trustworthy estimate of the total cost per mile of the railway. In 1871, when the works had been completed and opened from Moorgate Street to Mansion House, the expenditure on capital account by the District Railway Company for works and equipment of 7¼ miles of double-line railway, was stated in the Directors' report to have been £5,147,000, and by the Metropolitan Railway Company £5,856,000 for 10¼ miles, both amounts being subject to deduction in respect of surplus lands. It must be remembered that these figures, as already intimated, are of little value to an engineer, because they include items dependent, amongst other things, upon the market value of the shares, which, in the case of the Metropolitan Railway, ranged from 50 to 140, and in that of the District from 20 to 100, during the making of the lines. Many other companies experienced almost as wide vicissitudes of fortune whilst the Inner Circle was under construction; thus the Great Western Railway and the Brighton Railway shares each ranged from about 39 to 145, and the London and North-Western Railway from 98 to 174. The Author was actively associated with the construction of the railways from the commencement of the works until their completion to Moorgate Street and Mansion House in 1871, but can give no figures respecting the subsequent expenditure.

The traffic on the 3¾ miles of line first opened was a surprise to every one. In a letter from Mr. Fowler to Mr. Gladstone, dated March 1863, that is to say, a couple of months after the opening of

the railway, the Author finds a tabular statement of the number of passengers per mile per annum then travelling on different lines. The Metropolitan Railway had 2,792,200 passengers, as compared with 731,130 on the North London, 48,244 on the Brighton, 40,484 on the South-Eastern, 34,715 on the London, Chatham, and Dover, 20,183 on the London and South-Western, and 7,361 on the Great Western. Mr. Fowler found the proportion of first-class passengers to be 17 per cent., of second-class 31 per cent., and of third-class 52 per cent., and the receipts per mile per week, £629 11*s*. 5*d*. This result seemed too good to be true, and many people said it was merely "curiosity traffic." In 1867 the extension to Moorgate Street was opened, but previous to that date the receipts per mile per week fell within the following limits:—1863, from £410 to £683; 1864, from £496 to £785; 1865, from £641 to £910; and 1866, from £806 to £1,079.

The first length of the District Railway opened was the 2¼ miles from Kensington to Westminster, and the receipts averaged £300 per mile per week. When extended to Blackfriars, the earnings were about £400 per week. On both lines the subsequent increase in the main-line traffic has been enormous, but owing to the construction of branches these results are not apparent in the official traffic returns, which at the present time give, on the extended mileage, £586 per mile for the District and £633 per mile for the Metropolitan Railway. To show the growth of traffic it is only necessary to state that, whilst in 1863 the total number of passengers travelling by the "Underground Railway" was 9,455,175, and the receipts £101,707, in 1884 the number on the complete system was about 114,500,000, and the receipts about £1,012,000.

Engineering Features.

Contour of Ground.—The two leading features of a city railway, as of any other iron road, are the route followed and the level at which the rails are laid. As a rule, the route is determined by the desire to get to certain definite sources of traffic, whilst the levels are controlled by the physical configuration of the ground, the lines of drainage, and such things. The Metropolitan railways offer no exception to this rule. When a tract of country is closely covered by buildings of varying heights, and the natural watercourses are converted into covered sewers, it is difficult to form a general idea of the physical features determining more or less the character of the railway as regards level and gradients. In the case of the Metropolis, however, a sufficient record exists of the

previous condition of the country, and the excavations have in many instances afforded an interesting confirmation of traditions.

It is believed by competent authorities[1] that long before the Roman invasion some Celtic chieftain settled in the "City," and called his place of business "Lynn-din"—the Fort of the Lake. However this may be, it is certain that in early historical times the little hill on which the City stands was fronted by a wide stretch of tidal marsh land, extending to the base of the Surrey hills, and was flanked on the east by the Wall brook, and on the west by the Fleet river. Between the City and Westminster the river overflowed its north bank to only a limited extent, but westward of that it extended inland for at least a mile, forming the swamps of St. James's Park, Pimlico, Fulham, and other low-lying districts now traversed by London railways. To the north extended the rising ground culminating in the heights of Hampstead and Highgate, and the lesser heights of Campden Hill, Notting Hill, Maida Hill, Primrose Hill, Haverstock Hill, and Pentonville Hill. Within a couple of hundred yards of the Institution building the level of the footway even now is 8 feet below the highest tides, and at Hampstead the height is 443 feet above Ordnance datum. The highest ground traversed by the "Inner Circle" railway is at Edgware Road, and the lowest at the back of Victoria Street, Westminster, the respective heights being 103 feet and 8 feet above Ordnance datum. At Swiss Cottage the rails of the St. John's Wood branch climb to a height of 167 feet, and at the Kings Scholars Pond sewer in Victoria Street the District Railway dips to a depth of 9 feet below the same datum, or 3 feet below Thames low water.

Between the different spurs of the northern range of hills are drainage depressions, formerly clear running brooks or tidal channels, but now polluted sewers with tidal flaps for storm overflow. To the west of Kensington and Chelsea, rising in the high ground, but traversing chiefly the low-lying district, was the Bridge Creek, now known as the Counters Creek sewer, which is carried under the District Railway at Warwick Road in a flat-topped channel 7 feet wide and 8 feet high. As the level of the soffit is 9 feet below highest tides, the sewer top is of iron, calculated to resist a bursting pressure, there being no weight of ground overhead. Proceeding eastwards, the next stream met with was the West Bourne, rising on the western flank of Hampstead Hill, and flowing southwards to the Serpentine, and thence into the

[1] W. J. Loftie, F.S.A., "History of London."

Thames near Chelsea Bridge. This, now called the Ranelagh sewer, is carried under the Metropolitan Railway at Gloucester Terrace, and over the District Railway at Sloane Square station, the construction in the former case being a brick channel 9 feet wide by 8 feet high, with flat iron top, and in the latter a cast-iron tube, 9 feet in diameter, supported on wrought-iron girders of 70 feet span.

Next in order was the Ty-Bourne which flowed from Hampstead through Regents Park, thence by Marylebone Lane—whose strange windings are due to the houses having originally been built on the banks of the stream—and by the Green Park to the river between Vauxhall and Chelsea Bridges. At Baker Street the Metropolitan Railway is crossed by this stream under its present name of the Kings Scholar Pond sewer, the construction being a cast-iron oval tube resting on cast-iron girders. At Victoria Street the District Railway is similarly crossed, but the size of the tube is 14 feet by 11 feet in the latter case as compared with half those lineal dimensions at the northern crossing.

No stream of importance existed between the Ty-Bourne and the Fleet. The historical stream, known for the first portion of its course as the Hole-Bourne and for the latter portion as the Fleet, flowed from the Hampstead and Highgate ponds due south past King's Cross and along a deep tidal inlet into the Thames at Blackfriars Bridge. The sudden dip in the roadways at Holborn Valley and at Ludgate Hill remain as evidence of the former existence of this useful tidal navigable channel. Though a benefit in olden times it is hardly necessary to say that the Fleet river converted into a huge sewer constituted a serious difficulty in the construction of the Underground Railway. When building the retaining wall on the west side of Farringdon Street Station the Fleet, then carried in a slightly built brick sewer 10 feet diameter resting on the rubbish filled into the old channel, burst into the works and flooded the tunnel with sewage for a great distance. Again when constructing the District Railway at Blackfriars the Fleet had to be diverted and re-diverted, carried temporarily in syphons and otherwise carefully guarded as the large volume of water coming down it necessitated. No less than five crossings of the Fleet had to be dealt with, namely, two at King's Cross over the junction curves with the Great Northern Railway, one at Frederick Street over the Metropolitan Railway, another at the same spot over the widening lines, and finally a fifth under the District Railway at Blackfriars Bridge. The first four crossings were in cast-iron tubes of tunnel section, ranging in size from 9 feet by 8 feet to 10 feet by 10 feet, and the latter in two brick

channels 11 feet 6 inches wide by 6 feet 6 inches high with flat iron tops.

Levels and Gradients.—From the preceding brief sketch of the hills, valleys and streams of the country now covered by the buildings of the Metropolis, it will be possible to gather a very fair idea of the kind of line so far as levels and gradients are concerned that the "Inner Circle" of railway must be. Thus as the southern portion of the circle traverses the old bed of the river and the swamps of Pimlico and Bridge Creek, whilst the northern portion is on the slope of ground rising to Hampstead, it is clear that the general level of the District Railway must be very much lower than that of the Metropolitan. As a matter of fact, the average rail-level of the former is 13 feet below Thames high water, and of the northern part of the latter 60 feet above the same. Again, as the ground dips from north to south at a far steeper gradient than would be admissible on a railway, it is obvious that deep cuttings or tunnels must occur at the eastern and western portions of the "Inner Circle." In construction, cuttings 42 feet deep and a tunnel 421 yards in length are found at Campden Hill on the west, and cuttings 33 feet deep and a tunnel 728 yards in length at Clerkenwell on the east, the respective gradients to get down the sloping ground being about $\frac{3}{4}$ mile of 1 in 70 on the west, and 1 mile of 1 in 100 on the east. Further, as the valleys of the West Bourne and of the Ty-Bourne are crossed by the Metropolitan Railway, dipping gradients of 1 in 75 and 1 in 100 are required at these points. On the District Railway the rise from the Fleet Valley to the hill upon which the earliest parts of the city were built has to be surmounted, and it is done by a gradient of about $\frac{1}{2}$ mile of 1 in 100.

It will thus be seen that the levels and gradients (Plate 1, Fig. 1) of the "Inner Circle" railway have been determined by the original physical configuration of the ground, and that sewers, pipes and other specialities of city lines have had little connection with the question. The curves on the other hand, which have a minimum radius of 10 chains on the "Inner Circle" and $6\frac{3}{4}$ chains on the Great Northern branch, were fixed chiefly by the situation of the sources of traffic, and by property considerations.

Nature of Soil.—As regards character of ground cut through (Plate 1, Fig. 2), a considerable depth of made ground would necessarily be looked for at the east end, as the line is carried through a city founded perhaps two thousand years ago, and ravaged and burnt by Celts, Romans, Saxons, Danes, and Normans. In places as much as 24 feet of ruins and dust were cut through.

At the mouth of the Fleet the chalk-rubble foundation of an old fort was exposed, and at the Mansion House a masonry subway was discovered intact. Similarly, at Westminster, made ground was found to a depth of 18 feet. Remembering that between the City and Westminster the line is carried along the old bed of the river, mud and silt would naturally constitute the chief part of the excavation. At Charing Cross the walls of the covered way had to be carried to a depth of 25 feet below rail-level, or 37 feet below high-water, to secure a solid foundation; at the Temple the depth was 21 feet, and at Blackfriars 13 feet below rail-level. In the swampy ground farther west, originally flooded every tide, peaty deposits would be expected. Along Tothill Street a layer of peat 700 feet in length, varying in thickness from 7 feet to 2 feet, was cut through at a depth of from 8 feet to 16 feet below the present level of roadway. At Victoria Station a layer of similar peat, 200 feet long by 3 feet thick, was met with from 9 feet to 24 feet below the surface. A few feet below this peat the London Clay was found, and between Victoria and Gloucester Road stations the foundations either rest on the clay or close to it. Over the clay were varying depths of gravel and sand, heavily charged with water.

The Campden Hill tunnel arch is in gravel, sand, and brick-earth, but the London Clay rises at places within 6 feet of the top of the brickwork. No gravel nor sand was found at Queen's Road station, and very little between that point and Praed Street station. Thence to Gower Street station the foundations are generally on clay, overlaid with gravel, to some 4 feet above rail-level on the average. Practically no gravel was met with between Gower Street and Smithfield markets, where a layer about 10 feet in thickness was found interposed between the made ground and the clay. All the way from Smithfield to Moorgate good clean gravel was cut through, but the clay in all cases was within a few feet of rail-level.

The cuttings and longitudinal section (Fig. 2) of the railway show that, if what Sir Charles Lyell called the great ochreous gravel deposit of the Pleistocene epoch were swept away, the hills and valleys of the Metropolitan area would be practically unaltered in appearance. At what period in the remote past the sand, gravel, and brick-earth cut through by the railway in Westminster, at a level of 8 feet, and in Marylebone at 103 feet above Ordnance datum, were deposited no one can tell. It is believed, however, that England was then united to the Continent, that the present site of the North Sea was dry land, and the Thames a

tributary of the Rhine. It is proved by the remains of animals swept down by floods, and buried in the gravel at Windsor, Kew, and London, that roaming about the valley of the Thames must have been the mammoth, woolly rhinoceros, hippopotamus, straight-tusked elephant, lion, elk, bison, horse, bear, wolf, reindeer, and other animals. The gravels and sands met with in the railway cuttings may have been deposited at periods separated by thousands of years, for Sir Charles Lyell points out that sandpits, even in two adjoining fields, have contained the remains of distinct species of elephant and rhinoceros belonging to different parts of the Pleistocene epoch. Was man existent at this epoch? It is very generally believed that he was. Professor Boyd Dawkins, Assoc. Inst. C.E., asserts that man is proved to have been dwelling in the neighbourhood of London whilst the gravels accumulated high above the Thames, as well as while they were being formed at and below its present level. He refers to the fact that two centuries ago flint implements were found associated with elephants' bones at Gray's Inn Road, and have since been met with in the lower part of a 9-feet bed of gravel and sand overlying the London Clay at Acton, in the bed of the Thames at Battersea and Hammersmith, and elsewhere in the London district.

In making the excavations the gravel was generally found fairly dry to about the depth of the inverts of the adjoining sewers, but below that level large volumes of water had to be dealt with. Before commencing the cuttings sumps were sunk and lined with timbering or wrought-iron cylinders, 10 feet in diameter, and chain-pumps lifted the water into the nearest sewer. In June 1868, when the District Railway was being carried on to Westminster, there were sumps and pumps at Earls Court, Gloucester Road, Prince Albert Road, Old Brompton Road, Pelham Street, Moore Street, New Road, Sloane Square, Flask Row, Victoria Street, and Broadway, Westminster. The nominal HP. of the engines ranged from 4 to 20, and was 148 HP. in all, and the size of the pumps from 8 inches by 4 inches to 24 inches by 8 inches. It was stated at the time by the contractors that the cost of pumping, including renewals and repairs, amounted to £592 per month. From Kensington to Blackfriars, a length of 4¾ miles, the permanent drainage of the line is effected by pumping-engines placed at South Kensington, Victoria, Sloane Square, and the Temple stations.

In early days the Metropolitan Railway was familiarly spoken of as the "Underground Railway," to distinguish it from the numerous other projected Metropolitan lines where it was pro-

posed to carry the trains on a viaduct, as in the recently executed extensive system of "elevated" railways in New York. This characteristic of underground construction has been maintained on all the extensions of the Metropolitan Railway. On the "Inner Circle" the depth of rails below the surface of the ground ranges from 9 feet to 65 feet, and, as the cost of property precluded the use of ordinary open cuttings with slopes, the works necessarily consist of covered ways, tunnels, and open cuttings with retaining walls.

Covered Ways.—Under agreements with the Great Western and the Great Northern railways, the line from Paddington to Moorgate was laid with mixed gauge. The original covered way, therefore, required to be 28 feet 6 inches wide, as compared with 25 feet on the extensions where narrow gauge alone was laid. Plate 1, Fig. 3, shows the type of covered way adopted on the first portion of the Metropolitan Railway. It consists of a six-ring elliptical arch, of 28 feet 6 inches span, and 11 feet rise, with side walls three bricks thick, and 5 feet 6 inches high from the rails to the springing. No invert was constructed, nor was there any concrete under the 4 feet wide footings. Near Gower Street a short length of the side walls slid forwards, owing to the heavy engines having in the course of years worked up the clay formation, and withdrawn the support from the toe of the wall. This was stopped by putting some concrete inverts or struts between the walls. On the extensions the arch (Plate 1, Fig. 4) was five rings thick, and there was a concrete foundation 5 feet wide, and 2 feet 6 inches thick, under the side walls. Along the Thames Embankment a brick invert with concrete underneath was introduced, and on certain low-lying parts of the District Railway there was a concrete invert. Where a junction of main line and branch occurred in covered way a "bellmouth" was constructed. At Praed Street the "bellmouth" consists of the usual brick side walls, with an elliptical wrought-iron arch top, 28 feet 6 inches wide at one end, and 60 feet at the other, the ironwork much resembling the inverted hull of a large iron ship. At King's Cross the depth of ground permitted the adoption of a brick arched top. At Baker Street ordinary wrought-iron girders and jack-arches were used. Manholes or refuges were placed 50 feet apart on alternate sides of the line, and an 18-inch barrel drain was carried along the 6-feet way. Ordinary stock bricks and blue lias, or greystone lime, were used throughout.

Where there was not sufficient depth for a brick-covered way the construction shown by Plate 1, Fig. 5, was substituted. This

consists generally of brick and concrete side walls, in 8-feet bays of piers and recesses, and cast-iron girders from 1 foot 6 inches to 2 feet 6 inches in depth, spaced 6 feet to 8 feet apart, with two- and three-ring jack-arches between. In places wrought-iron girders were used, but though more trustworthy than cast iron whilst new, they are exposed to greater risk from hidden oxidation. Experience has shown the trouble and cost of maintaining ironwork exposed to the atmosphere of an underground railway to be such, as would justify a considerable increase in the first cost by substituting brickwork and deep cuttings for ironwork and shallower construction. The 2 feet 6 inches cast-iron girders were tested with a load of 45 tons applied at the centre, and the 1 foot 6 inches girders with 35 tons, which loads considerably exceed those to which the girders are liable in practice. No failures or indications of failure have occurred with any of the iron-topped covered ways.

The method of executing the covered ways varied at different times and under different contractors. On Messrs. Smith and Knight's contract (1861–63) for the Paddington to Euston Square portion of the original Metropolitan Railway the excavations were got out the full width of 33 feet 6 inches, and timbered right across. At South Wharf Road (Plate 1, Fig. 6) there were heavy buildings on each side, and the road traffic had to be maintained overhead during the construction of the covered way. Balks of timber 16 inches square, and 43 feet long, spaced 5 feet apart from centre to centre, were first laid across the site of the proposed cutting, and planked for the temporary roadway, with one longitudinal and one transverse row of 12 inches by 6 inches timbers. At a depth of 2 feet below the balks was a line of 12 inches by 6 inches walings, 12 feet long, with 13 inches by 13 inches struts at each end and at the centre. Below this at a depth of 10 feet was another line of similar walings strutted in the same manner, and between the two were runners about 12 feet long, and 12 inches by 3 inches scantling. For the remainder of the depth the ground was supported by $\frac{3}{4}$-inch poling boards, and four lines of walings strutted to 10 inches by 10 inches verticals, butting on the lower row of main struts at the top end, and on the ground at the lower end. When the whole of the excavation was complete, the side walls were built to 4 feet above springing, and iron centres were then fixed 6 feet apart, and the arch turned. The cost of timbering at this point was 7*d.* per cubic yard of excavation.

In the heavier ground on Mr. Jay's contract (1861–63), east of Euston Square, the excavations were also got out the full width, but the 12-inch by 7-inch walings, 13 feet in length, were spaced 7 feet

apart, from centre to centre, from top to bottom of the excavation and strutted with 11-inch square balks at each end and at the centre (Plate 1, Fig. 6a). Although the greatest care was exercised in following up the excavations with the runners, and tightly wedging the same to the walings and struts, there was very frequently a draw of the ground towards the cutting, and cracks, 1 inch to 2 inches in width, would appear in walls distant 40 feet to 50 feet from the trench. Work was carried on day and night, and in a 30-feet deep cutting the advance was about 22 yards per week at each face.

A year after the works had been in progress a return was obtained of the cost of excavation in a 22 feet 3 inches deep cutting along the Marylebone Road. The work was executed in three lifts, the top one being 5 feet deep and 37 feet long, the middle 6 feet and 27 feet long, and the bottom 11 feet 3 inches in depth and 12 feet long. The materials were 18 inches road metal, 4 feet clayey gravel, 5 feet loam, and then coarse gravel and sand down to the London Clay on which the footings rested. There were twenty-one excavators in the top lift, sixteen in the middle, and twenty-one in the bottom, and the cost of labour in getting, filling and timbering, exclusive of superintendence and general charges in the respective lifts, was 1*s.* 2½*d.*, 9½*d.*, and 7½*d.* per cubic yard. Adding 3*d.* per cubic yard for use and waste of timber, the average of the whole amounted to 12½*d.* per cubic yard. Carting to spoil cost 2*s.* 3*d.* per cubic yard, but on the other hand, part of the gravel was reserved for ballast and concrete, and a large quantity was sold at 2*s.* 9*d.* per cubic yard. Taking the latter points into consideration, the Author is of opinion that a great deal of the heavily-timbered excavations on the Metropolitan Railway cost the contractors only 1*s.* per cubic yard as an average, although the clay excavations at the same point would certainly cost them as much as 3*s.* 4*d.* for labour and material alone, or say 4*s.* per cubic yard, including general charges and contingent risks.

In later days, when the District Railway was being constructed, the general practice was not to timber the entire width of covered way, but to sink a couple of 6-feet wide trenches for the side-walls, to build the latter up to 4 feet above springing, take out the excavation full width down to that level, fix the centering, turn the arch, and finally take out the "dumpling." The labour and use and waste of timbering the narrow trenches amounted to about 9*d.* per cubic yard in gravel and 13*d.* in heavy ground.

At average contract prices the cost of the different types of covered way per lineal yard would be as follows:—

1.—ARCH COVERED WAY 25 feet wide in 25 feet CUTTING.

				s.	d.	£.	s.	d.
65	cubic yards	excavation to spoil.	at	4	0	13	0	0
30	„	„ refilled	„	2	6	3	15	0
15	„	brickwork	„	24	0	18	0	0
7	„	concrete	„	7	6	2	12	6
11	sup. yards	asphalt	„	2	9	1	10	3
1½	lin. yard	4-inch drain pipe and bends				0	4	3
1	„	18-inch barrel drain				0	15	0
						£39	17	0

2.—ARCH COVERED WAY 28 feet 6 inches wide in 25 feet CUTTING.

	£.	s.	d.
At preceding prices the cost per lineal yard	47	5	0

3.—GIRDER COVERED WAY 25 feet wide in 17 feet 6 inches CUTTING.

				s.	d.	£.	s.	d.
83	cubic yards	excavation to spoil	at	4	0	16	12	0
12½	„	brickwork	„	24	0	15	0	0
12	„	concrete	„	7	6	4	10	0
13	sup. yards	asphalt	„	2	9	1	15	9
6½	lin. yards	drain pipe and blends	„	..		0	13	3
1	„	barrel drain	„	..		0	15	0
32	cwt.	cast-iron girders	„	8	0	12	16	0
						£52	2	0

Tunnels.—There are three tunnels on the "Inner Circle": the Clerkenwell tunnel, 728 yards long, on the original Metropolitan Railway; the "Widening" tunnel, 733 yards long, parallel to the preceding, and the Campden Hill tunnel, 421 yards in length. The two former are 28 feet 6 inches wide, with semicircular arched top, generally 6 rings thick, springing 4 feet 6 inches above the rail level. The latter is 25 feet wide with semicircular top and springing 5 feet 6 inches high. All the tunnels have four-ring inverts. A portion of the 28 feet 6 inches elliptical top covered way without invert was driven as a tunnel under the Euston Road (Plate 1, Fig. 6a), although the depth of ground over the crown bars was as little as 6 to 9 feet.

The Clerkenwell tunnel, 728 yards in length, was commenced in November 1860, and finished in May 1862. There were eleven temporary shafts, and one permanent shaft, and the depth to rail-level ranged from 29 feet to 59 feet. All of the tunnel was in London Clay, which extended from 2 feet to 11 feet over the arch, and above the clay was a bed of sand and gravel charged in places with water.

The "Widening" tunnel was begun in November 1865 and completed in May 1867. At the east end the rails dipped to pass under the original line, so the maximum depth was increased to 55 feet. Three ventilating shafts are spaced between the east tunnel mouth and the signal station, where there is open cutting for 30 feet, followed by a further length of 350 yards of tunnel-section, not driven but executed on the "cut and cover" system.

The Campden Hill tunnel, commenced in October 1865, was finished in January 1867. There was a mass of wet gravel and sand over this tunnel, extending generally down to the springing. There are no permanent ventilating shafts, but a 30-feet length of open cutting occurs at the intermediate signal station.

As a settlement in the ground, over and contiguous to the tunnel, took place in most instances, a careful investigation of the subject was made by Mr. Morton, the Resident Engineer, on the "Widening" tunnel. It was found that from the commencement of the length to the getting in of the top sill there was a settlement of $\frac{3}{4}$ inch, and from that time to the underpropping of the bottom sill, or completion of timbering, a further 2 inches. Owing to the compression of the joints in the arch after the striking of the back props when the weight first came upon the green brickwork, there was a movement of $\frac{3}{4}$ inch, which had increased to $1\frac{1}{2}$ inch twelve hours after keying. A further settlement of $1\frac{1}{4}$ inch in the arch, and $1\frac{3}{4}$ inch in the side walls and inverts, where the supporting props carried the centres, made up a total of $7\frac{1}{4}$ inches. It may be mentioned that no heading was driven in advance of the "Widening" tunnel, except a small one of 5 feet by 4 feet for getting in the first two crown bars. The tunnel was timbered in the usual way, and there were on the average eight 12 inches square crown bars and sixteen round bars at the haunches and sides of the tunnel.

The cost of labour in mining a 9-feet length was £33 for the 270 cubic yards of excavation, or 2*s.* 6*d.* per cubic yard. To this must be added the miner's profit, the cost of timber, tools, and shafts, the raising earth and carting to spoil, and the head contractor's profit, which together brought up the contract price to about 7*s.* 6*d.* per cubic yard for the excavation measured net. The actual cost of bricklaying in a 9-feet length, including loading the bricks into skips at top and delivering them to the bricklayers, was £24 for the 90 cubic yards of brickwork in the seven-ring tunnel and filling over the crown, or at the rate of 5*s.* 4*d.* per cubic yard. About 14 cubic yards of mortar and thirty-four thousand bricks were used in the 9-feet length, and adding the cost of these to

that of the centering and other items, and the contractor's profit, the average contract price of 30*s.* per cubic yard for the net quantity of brickwork, exclusive of filling between bars, will be arrived at. On the preceding basis the contract price per lineal yard of tunnel 28 feet 6 inches wide would be about as follows:—

		s.	*d.*		*£.*	*s.*	*d.*
85 cubic yards net excavation at		7	6	. . . . . .	31	17	6
25 „ „ brickwork „		30	0	. . . . . .	37	10	0
					£69	7	6

On the average, sixteen miners and labourers, working nine shifts each, excavated the 9-feet length, and twelve bricklayers and labourers, working seven shifts, did the brickwork.

In carrying out the Campden Hill tunnel a bottom heading, 9 feet square in the clear, was constructed to drain the gravel and otherwise facilitate operations. The tunnel was driven in lengths of 12 feet or 12 feet 6 inches, and was timbered in the usual way, except that the top, on account of the looseness of the ground, was supported in advance of the poling by light sheeting driven into the fine sand over the crown. When one of the 16 inches or 18 inches round bars was in position, a number of 3-feet by 6-inch by 1-inch boards, having one end sharpened, were driven over the top of the bar, and square to the same into the ground, and the rear ends of the boards were packed up to the adjoining polings, and so temporarily held in position until the next bar was fixed. Sometimes the ground was double piled in this manner; but there was the greatest difficulty in stopping the run of the sand, and as the crown bars often came down 12 inches, considerable settlement and damage to property resulted. The engineers and contractors differed as to the propriety of the mode of carrying out the works. It was contended by the engineers that in tunnelling through property, as little ground should be disturbed at a time as possible; that the lengths should be rather 6 feet than 12 feet; that the brickwork should closely follow up the excavation, and that the driving of a large heading for a long time in advance of the tunnelling necessarily unsettles the ground, and renders it less able to support the subsequent tunnelling operations. Some four or five months after the Campden Hill heading had been standing, the increasing pressure of the ground told severely on the timbering. In several instances the side trees were broken and crushed down, so as to form a knee bulging towards the interior of the heading. The head trees followed the side trees, and a settlement of 4 inches or 5 inches was common. Many of

the bottom sills tilted over on one side and endangered the settings; so that, to prevent the headings falling in, a considerable length had to be double timbered, which prevented the passage of the wagons. The heading was almost wholly in clay, which was softened by water percolating through fine fissures from the gravel overhead; indeed, a large quantity of water could be observed running down the sides of the heading behind the poling boards.

Owing to a strike of the miners a 76-feet length of the Campden Hill tunnel was built in open cutting; but the results were not satisfactory. In order to keep the wagon-way free the invert was left out at first, and the side walls came in 5 inches. Again, the filling in of the broad trench over the arch with nearly 30 feet in depth of made ground caused a draw in the ground, and a general settlement in adjoining property. If executed in this manner the timbering should be left in, and other precautions taken; but in any event, owing to the nature of the ground, it would have been difficult to have avoided all damage to property at Campden Hill. On the original Metropolitan Railway the clay was hard and dry, and the difficulties were much lessened. At Clerkenwell Mr. Jay drove the Metropolitan Railway tunnel along the Bagnigge-Wells Road for a length of 160 yards within 10 feet of the heavy boundary wall of the prison, with hardly any sign of settlement, and he was equally successful in passing within 8 feet of the Clerkenwell workhouse. The "Widening" tunnel was driven under the contractors' office in Exmouth Street, without any apparent damage to the exterior of the building, and with but slight internal indications of settlement. However, with the utmost precautions, tunnelling through a town is a risky operation, and settlements may occur years after the completion of the works. Water-mains may be broken in the streets and in the houses, stone staircases fall down, and other unpleasant symptoms of small earthquakes alarm the unsuspecting occupants. At the prices already given for the 28 feet 6 inches tunnel, the cost per lineal yard of the 25-feet tunnel would be as follows:—

	s.	d.	£.	s.	d.
76 cubic yards net excavation at	7	6	28	10	0
23 „ „ brickwork „	30	0	34	10	0
			£63	0	0

It is hardly necessary to remark that heavy contingencies have to be added to tunnel estimates when, as in the case of the Metro-

politan Railway, the Contractors assume the responsibility of damage to adjoining property.

Open Cuttings.—At rail-level the width of the open cutting is 28 feet 6 inches on the old line and 25 feet on the extensions. The same type of retaining-wall has been adopted throughout (Plate 1, Fig. 7), namely, a brick and concrete recessed wall in 11-feet bays, with piers 3 feet and recesses 8 feet wide on the face. The batter is 1½ inch to the foot, the depth of foundations below rail level 5 feet, and the usual thickness of the walls at the base about 40 per cent. of the height. Occasionally, when the depth is considerable, the thickness has been reduced, and one or two rows of cast-iron struts have been introduced. Plate 1, Fig. 8, shows the open cutting on the original Metropolitan Railway at Acton Street, and Plate 1, Fig. 9, a similar work on the extension.

At ordinary contract prices the cost per lineal yard of open cuttings and retaining walls would be as follows:—

OPEN CUTTING 25 feet wide and 25 feet deep.

	s.	d.	£.	s.	d.
143 cubic yards excavation at	4	0	28	12	0
20 „ brickwork „	24	0	24	0	0
36 „ concrete „	7	6	13	10	0
6 lin. yards drain pipe and bends			0	12	6
Cost per lineal yard			£66	14	6

With one row of cast-iron struts, cost £55 2*s.* 9*d.*

OPEN CUTTING 25 feet wide and 42 feet deep, with Two Rows of Cast-iron Struts.

	s.	d.	£.	s.	d.
220 cubic yards excavation at	4	0	44	0	0
30 „ brickwork „	24	0	36	0	0
40 „ concrete „	7	6	15	0	0
8 lineal yards drain pipes and bends			0	15	6
30 cwt. cast iron			12	0	0
Cost per lineal yard			£107	15	6

In executing open cuttings, the practice at first was to timber the whole width of excavation, and follow up with the temporary rails and wagons to convey the material to spoil-banks on the Great Western and Great Northern railways. Subsequently the more usual course was to sink trenches for the retaining walls, carting away the stuff to spoil, and afterwards removing the dumpling in railway-wagons. Comparatively light timbering

served for the trenches. Walings 9 inches by 3 inches by 13 feet long, spaced 3 feet apart, and struts from 7 inches square at each end and at the centre, sufficed as a rule to uphold the polings or the 12 inches by 3 inches runners used for the upper part of the excavation and the 1-inch poling boards below, but in places heavier timbering was adopted. The Author refers to his Paper on "The Actual Lateral Pressure of Earthwork"[1] for some further particulars respecting the works in open cuttings.

Stations.—There are twenty-seven stations on the 13 miles of "Inner Circle" railway. As already explained, it was the original intention to make the stations, as well as the railway, strictly "underground," and Baker Street, Portland Road, and Gower Street stations were so constructed. Plate 2, Figs. 10 and 11, show the construction at Baker Street. A segmental arch, 45 feet 1 inch span, and 10 feet 4 inches rise, six rings thick at the crown and twelve rings at the springing, where pierced with openings for light and ventilation, extends throughout the entire 300-feet length of station. When the mixed gauge was in operation the width of the platforms was 10 feet, but they are now widened. A special feature in the structure is the extreme lightness of the abutments, which are only 5 feet 6 inches thick at the piers and 2 feet 3 inches at the back of the recesses. The excavations, 56 feet 6 inches in width, were timbered right across with three rows of main struts 10 inches square, spaced about 4 feet 6 inches apart longitudinally, and 12 inches by 6 inches walings supporting runners at the top, and poling boards at the bottom of the excavation. The contract prices were 4*s.* 6*d.* per cubic yard for earthwork to spoil, 7*s.* per cubic yard for concrete, the gravel being on the spot, and 25*s.* 6*d.* for brickwork, with white brick facing. Including booking offices, street restorations, and all contingent works, the cost of an underground station, such as Baker Street, amounts to £18,000 more than that of the same length of covered way.

Where the local conditions admitted it, the stations were placed in open cuttings with vertical retaining-walls, elliptical arched iron roofs (Plate 2, Fig. 12), and short lengths of open cutting at each end for ventilation. The platforms are 300 feet long by 15 feet wide, and the roofs 50 feet 6 inches span. On the average the cost of such a station, beyond that of the corresponding length of ordinary railway, ranged from about £14,000 in the instance of Queen's Road, Bayswater, to £22,000 in that of Victoria. At

[1] Minutes of Proceedings Inst. C.E., vol. lxv., p. 140.

St. James's Park station the cost price of the roof, 330 feet in length by 50 feet 6 inches span, was £4,040, or £24 5*s.* per square measured on the flat. There are 79 tons 18 cwt. of wrought iron, 52 tons 13 cwt. of cast iron, one hundred and sixteen squares of zinc, and ninety-five squares of rough plate glass in the roof referred to. The general price of the booking offices, including gas and all other fittings, was 10½*d.* per cubic foot. Separate entrance and exit staircases and galleries are provided at the stations, but not always used, as they involve a double staff of ticket-men. Ordinarily the width of stairs is 6 feet, and the treads are 11 inches by 6 inches.

At the Temple (Plate 2, Fig. 13) a special kind of station had to be devised, as the agreement with the Duke of Norfolk precluded the use of a raised roof. At the Mansion House (Plate 2, Fig. 14) also the works are of an unusual character, as they lie partly under the subways and vaults of Queen Victoria Street. The wrought-iron columns carrying the girders are connected by continuous walls of brickwork in cement and timber copings, with a view to deflect the blow of any de-railed train.

Permanent Way.—From Paddington to Farringdon Street the permanent way originally consisted of a 60-lbs. wrought-iron flange rail, with case-hardened top, secured to 13 inches by 6½ inches longitudinals by ⅝-inch fang-bolts. A steel rail of the same section was next adopted, and carried the heavy traffic safely, though the wear was great and the trouble of renewals considerable. On extending the line to Moorgate Street in 1863, an 83-lbs. steel flange-rail, laid on 10 inches by 5 inches cross-sleepers, was substituted for the original light longitudinal sleeper-road. The price paid for the first lot of 83-lbs. rails was £18 15*s.* per ton, and for the double-line road complete, including ballasting, £5 per lineal yard, or nearly £9,000 per mile. The flange-rail was used until 1873, when it was gradually replaced by a chair road.

Special Works.

With present experience the construction of underground city railways need cause the engineer or contractor but little anxiety compared with that encountered by the pioneers of such works twenty-five years ago. It is known now what precautions are necessary to ensure the safety of valuable buildings near to the excavations; how to timber the cuttings securely, and keep them clear of water without drawing the sand from under the foundations of adjoining houses; how to underpin walls, and, if necessary,

carry the railway under houses and within a few inches of the kitchen floors without pulling anything down; how to drive tunnels; divert sewers over or under the railway, keep up the numerous gas and water mains, and maintain the road traffic when the railway is being carried underneath; and finally, how to construct the covered way, so that buildings of any height and weight may be erected over the railway without risk of subsequent injury from settlement or vibration. The Author from personal experience can testify that many of the expedients, which now appear obviously safe and proper, received much anxious discussion and criticism before they were decided upon twenty-five years ago. Such questions as the admissible stress on brick arches loaded on one haunch only; the extent to which expansion and contraction of iron girders would affect buildings carried by them, the ability of made ground to resist the lateral thrust of arches, and a multitude of similar problems had to be dealt with tentatively at first, and with increasing boldness as experience was gained. Novel problems and special works occur in abundance on the "Inner Circle Railway," but only a few can be touched upon in the present Paper.

Sewers.—Siphons were rarely resorted to for carrying sewers across the railway. An early constructed one occurs at Stafford Street, where a 5 feet by 3 feet sewer is carried in a 3 feet diameter cast-iron siphon 81 feet long, with a dip of 14 feet under the railway, flushing sluices and mud-doors being provided to minimise the evils of deposit. At Blackfriars the Fleet sewer was temporarily siphoned under the line, and the same course was followed with some other sewers. As a rule, however, sewers if not wholly diverted were either carried over the line in a cast-iron tube, or under it in a brick channel with iron top. Plate 2, Figs. 15 and 16, show the Fleet crossing of the Metropolitan Railway and the "widening" lines at Frederick Street. The sewer, 10 feet 2 inches wide by 9 feet 7 inches high, is carried in a cast-iron built-up tube, supported on cast-iron girders. At each end the ironwork is built into the brickwork, and though the effects of expansion were somewhat feared, no trouble has arisen from that cause. At Farringdon Street the Middle Level Sewer crosses the station yard in a wrought-iron tube 8 feet 9 inches in diameter, 130 feet long, supported on wrought-iron girders. Provision for expansion was made by connecting the wrought-iron tube and brick sewer with an assumedly flexible sheet-lead joint, but whether this still exists or has long since disappeared from galvanic action, the Author cannot say. At Sloane Square he substituted a cast-iron tube 9 feet in diameter

and 86 feet long, and a flexible wrought-iron expansion joint (Plate 2, Fig. 17), as offering a greater chance of durability. Many of the smaller sewers were carried in pipes of oval section, cast in about 9-feet lengths, and bolted together. One at Gloucester Road, 85 feet long, was made up of ten lengths of 5 feet 6 inches by 3 feet tube, $1\frac{1}{8}$ inch thick, securely bolted together; but in all cases, however strong the sewer castings might be in themselves, girders were introduced to carry the sewer. Occasionally cast-iron troughs with skew ends were let into the brickwork, and sometimes a pair of girders with flat plates resting on the bottom flanges were introduced for carrying sewers and pipes across the arch. The sewage was conveyed temporarily in well calked wooden troughs, round which in some cases the permanent cast-iron sewers were built. To avoid siphons the side walls were often underpinned and the inverts lowered for a considerable length; thus at Gloucester Terrace the Ranelagh sewer (Plate 2, Fig. 18) was underpinned to a depth of 8 feet, and for a length of 1,000 feet to carry it under the railway and into the Middle Level Sewer. A noticeable piece of special construction in connection with sewers occurs at Blackfriars (Plate 2, Fig. 19), where the Low Level sewer 8 feet 6 inches in diameter, crosses diagonally under the railway. As this sewer is subject to hydrostatic pressure, wrought-iron hoops are built into the brickwork to resist the bursting stress.

Gas and Water Mains.—These were generally carried across the line in cast-iron troughs or similar construction. Occasionally very expensive diversions were necessary; thus, in passing Broad Sanctuary no less than 2,000 feet of gas-mains, ranging from 14 to 30 inches in diameter, had to be diverted, and in the simple crossing of High Street, Kensington, 600 feet of gas and water-pipes, from 3 to 30 inches in diameter, blocked the way. Where the covered way was deep enough to clear the existing mains, the latter merely required to be slung temporarily from heavy balks, whilst the works were executed beneath.

Temporary Roadways.—In the case of interference with busy thoroughfares, the authorities sometimes required the whole width of roadway to be kept open for vehicular traffic. Whether the whole or only a part of the roadway were dealt with, the principle was the same, namely, to throw heavy timbers across the railway, occasionally extending them up to the front walls of the houses on either side, to serve as struts, and to plank these timbers for the roadway, and support them with props as the excavation proceeded underneath. No difficulty was found even in the earliest days in maintaining the street traffic during the progress of the

works, but the cost was necessarily considerable, amounting sometimes to 5*s.* per superficial foot of temporary roadway, or more than the brickwork of the covered way itself.

Supporting Buildings.—In passing a sound building on a good foundation, the only precaution found necessary was to execute the work in short lengths, with carefully timbered trenches quickly followed up by the concrete and brickwork of the retaining-walls or covered way. Plate 2, Figs. 19 to 21 are examples of work so executed without any resultant cracks in the buildings. Old buildings were always substantially shored, and in many cases underpinning was resorted to previous to the commencement of the railway works. The first piece of work of the kind on the Metropolitan Railway was carried out in 1861 by the late Mr. T. Armstrong, the contractors' agent for the greater portion of the line from Paddington to Moorgate, and the one, therefore, who had the earliest experience of the specialities of underground railway construction. At the corner of Edgware Road the arch-covered way ran foul of some important arched vaults which it was necessary to maintain intact, although the brickwork cut nearly through the arch of the railway. This case of underpinning one arch by another arch was effected without causing the slightest severance of the vaults from the buildings, and confidence in the ability to carry out such works was thus usefully strengthened. In 1867 Mr. Armstrong successfully executed the very extensive underpinning works at the Farringdon Station yard. Here the retaining-wall, 620 feet in length, 32 feet high and 11 feet thick, was underpinned to a depth of from 10 feet to 24 feet without causing the smallest movement in the ground, which was clay with pockets of very fine sand, or in the Fleet sewer running parallel to and within 15 feet of the back of the wall. At the same spot the abutments of Ray Street bridge, a heavy brick arch of 50 feet 6 inches span, were similarly underpinned (Plate 2, Fig. 22), as was also the tunnel mouth of the railway (Plate 2, Figs. 23 and 24). The abutments of Ray Street were underpinned in 4-feet lengths, containing 34½ cubic yards of excavation, which cost for labour £15 16*s.*, and for timber £5 10*s.*, or say 12*s.* 6*d.* per cubic yard, exclusive of profit and contingencies. In 1866 Mr. T. Walker underpinned sixteen houses in Conduit Street, and very many such works will be found on the "Inner Circle." Sometimes the underpinning has been attempted in long lengths, such as 12 feet, but extensive damage to property resulted.

When the original line had to be carried under a couple of houses in Park Crescent the portions of the structures immediately over the

railway, weighing about 1,200 tons, were pulled down and rebuilt on wrought-iron box-girders. Some four years after, when the line was being extended through Pembridge Square (Plate 1, Fig. 24a) the houses were kept up; the side walls of the railway were constructed in short lengths, and main girders of 25-feet span slipped between the walls of the houses at convenient places, supported a number of short cross girders pinned through the walls. At Park Crescent only a floor of old ship-timber separates the kitchens from the railway, but at Pembridge Square brick jack-arches intervene.

Since the completion of the line very many buildings have been erected over it at different points. In some instances the covered way was originally constructed of sufficient strength to carry buildings, and in others it was subsequently strengthened. Where the depth was sufficient for an arch, brick-covered ways were adopted in preference to iron-girder constructions, on account of the smaller cost and increased durability. The first instance of building over the railway was at Edgware Road, where the line of frontage crossed the arched covered way on the skew for a length of 80 feet. As constructed the arch was not strong enough to carry the unequally-distributed weight of the houses, and four wrought-iron girders were consequently thrown across the 28 feet 6 inches covered way under the main walls. It was contended before an arbitrator that as part of the buildings rested on elastic girders, part on the brick arch, and the remainder on the adjoining ground, cracks would necessarily ensue from the shaking and vibration of this mixed construction. The Author held that if the walls were built in mortar and run up quickly no evil results would ensue, but clearly, in the absence of experience, no one could predict definitely what would happen. As a matter of fact no inconvenience resulted in the case referred to or in any similar cases. At King's Cross, where a 28 feet 6 inches and a 25 feet brick covered way, with central pier, are crossed diagonally by two lines of frontages for a length of 130 feet, the following plan was adopted by the Author: Over the arch, which had been built some years before, were placed wrought-iron girders spanning the 28 feet 6 inches covered way, and cantilevering over so much of the 25-feet way as the line of frontage demanded. These girders were kept a few inches clear of the arch, and upon them the main walls of the houses were built. When all deflection of the girders under the dead weight of the building had ceased, the space between the lower flanges and the arches was solidly built in, so that all live loads on the floors would be supported by the brick arch. By this contrivance, which proved quite

satisfactory in practice, the weight of the girders was reduced by about one-half.

As an instance of the confidence which experience gives, it may be mentioned that although in 1861 the doubts entertained by the engineers as to the behaviour of a compound brick and iron structure were such as to lead to a timber front being put to the Edgware Road Station building, where it rested on a 49-feet span girder, yet, in 1865, when the extension to Moorgate was executed, no hesitation was felt in trusting an elaborate brick and ashlar face wall, weighing 1,300 tons, to a continuous girder 135 feet in length.

At Westminster and at Blackfriars Stations there are buildings some 80 feet in height carried on girders, spanning the rails and platforms; and at Victoria Street, Westminster, the arched covered way from eight to ten rings thick, runs for a length of 400 feet under the heavy buildings since constructed. It would be useless to tabulate the numerous cases similar to the preceding, but the Author may sum up his experience and practice as follows:—(1) In the instance of buildings carried on girders, adopt a working tensile stress of 6 to 7 tons per square inch, according to the height and solidity of the wall resting on the girder, and interpose a layer or two of tarred felt between the ironwork and brickwork. (2) In the case of buildings carried on arches, spread out the footings of the walls and assume the effective width of foundation, or length of covered way over which the weight of a wall will be distributed, as equal to double the thickness of the wall plus double the thickness of the arch; construct the curve of equilibrium due to the weight of building and arch, and so proportion the number of rings of brickwork that an ideal arch, following the form of the line of thrust, and of a thickness corresponding to a uniformly distributed stress of 8 tons per square foot, would fall within the actual arch. This empirical rule has answered well in practice, and is as scientific as any formula based on the false assumption of a constant modulus of elasticity, which the Author has never found to obtain in his own experiments. It may be added, that houses 43 feet in height from foundation to parapet, and having three floors exclusive of basement, were allowed to be built on the ordinary five-ring covered way, the footings being spread out to a width of 3 feet by brickwork or concrete.

Smithfield Market.—In connection with the extension to Moorgate Street, the basement of the large Meat Market at Smithfield was constructed by the railway companies. The floor of this

market, 625 feet long by 240 feet wide, affords perhaps the largest example in existence of wrought-iron girders and brick arch construction. Twenty continuous main girders, each 245 feet in length, span the width of the market, and carry longitudinal girders 630 feet in length, spaced 7 feet 6 inches apart, with jack arches two rings thick, and 1 foot 9 inches rise between them. The main girders, loaded with from 8 to 9 tons per lineal foot, are supported by wrought-iron columns at intervals ranging from a few feet to 58 feet. It is noteworthy that no provision whatever was made for expansion in any of the ironwork, which convenient course was amply justified by experience, no indications of movement being observable in the brick walls or floor. Brick vaults, in 15 feet bays, surround the market and retain the earth, the depth of which from floor to rail level is 24 feet. Extensive hydraulic plant was provided to work the sidings, turn-tables, and hoists, and a special approach road affords access for vehicular traffic to the lower level.

Bellmouth at King's Cross.—As first constructed, the single line eastern junction curve from the Great Northern Railway joined the Metropolitan Railway 150 yards west of the King's Cross Station, and the western curve, crossing the eastern curve on the level, joined the Metropolitan 80 yards further east. The whole of the works being in covered way, two bellmouths, 28 feet 6 inches span at one end and 45 feet 6 inches at the other, had to be built. When in 1867 the "widening" lines were executed, and a junction was made with the Midland Railway, it became necessary to do away with the existing bellmouth, and substitute two others; and, as this had to be effected whilst the traffic was running, the works were both novel in design and difficult of execution. Plate 2, Fig. 25, illustrates one of the peculiarities of construction. A longitudinal slice was cut off the old bellmouth, and the lateral thrust of the new arch distributed by means of castings built in the brickwork of the central pier. At other cross-sections different expedients were resorted to for maintaining temporarily and permanently the stability of the strangely-shaped covered way. Cast iron was also introduced in combination with a brick covered way on the St. John's Wood line. As the depth was insufficient for the ordinary 32-feet span covered way, the top of the arch was flattened to a radius of 40 feet, and castings, 18 feet long and 2 feet 6 inches deep, with a camber of 1 foot, were built into the brickwork every 6 feet. Cast-iron arches and struts were also built in at Baker Street and Gower Street stations, and other points where sufficient strength could not otherwise be obtained.

The Author has now finished his outline sketch of the general history and engineering features of the 11¼ miles of Metropolitan and Metropolitan District Railway, with the construction of which he was himself personally connected. He is the better reconciled to the obvious imperfections of his work by the reflection, that its very incompleteness may tempt other engineers, who have been engaged on the Inner Circle Railway, to fill in his outline sketch with such details as they individually may consider of special interest to members of the Institution. He would only add that the Chief Resident Engineers were, on the Metropolitan Railway works from Kensington to Moorgate, Mr. William Morton, and on the District Railway works from Kensington to Mansion House, Mr. Frederick Cooper, MM. Inst. C.E.

The Paper is accompanied by numerous drawings from which Plates 1 and 2 have been engraved.

(*Paper No. 2060.*)

"The City Lines and Extensions (Inner Circle Completion) of the Metropolitan and District Railways."

By John Wolfe Barry, M. Inst. C.E.

The work of completing the "Inner Circle" of London Railways, although the length of railway is not great, is a work which probably merits separate description, and which fitly comes in continuation of Mr. Baker's Paper on "The Metropolitan and Metropolitan District Railways."

There is, the Author believes, no other example of a circular railway in a large town. The works of construction possess, owing to its situation, features of special interest, and the problems involved in its working are to some extent unique.

Historical.

Mr. Baker's Paper leaves the work with which he was connected on the north at Moorgate Street, and on the south at Mansion House, both of which were, at the time to which he refers, terminal stations. As explained by Mr. Baker, the completion of the circle was authorized as long ago as 1864, but financial and other difficulties prevented its realization, and the powers of the Act of 1864 lapsed by efflux of time.

The completion of the circle was, however, always kept in view by both the Metropolitan and the District Companies, and Parliament was at all times in favour of the undertaking. The Metropolitan Company gradually extended their line in 1875 from Moorgate to Bishopsgate, of which portion Mr. E. Wilson, M. Inst. C.E., was engineer, and subsequently, in 1876, from Bishopsgate to Aldgate, of which portion Mr. Francis Brady, M. Inst. C.E., was engineer. The Metropolitan Company also, under an Act of Parliament of 1877, bought land southward of Aldgate, and were authorized to further extend the line under High Street, Aldgate, to the land in question. All these were steps towards the carrying out of the original intention of extending the Metropolitan Company's line to Tower Hill, for which the original Act of Parliament

was obtained in 1864. In fact though the powers of that Act expired, Parliament refused to relieve the Metropolitan Company of its obligation to make the line to Tower Hill, and, as occasion served, that Company gradually took steps towards the fulfilment of that work.

The original Act of the District Company of 1864, authorized the construction of a line from Mansion House to meet the Metropolitan Company's line at Tower Hill, but financial pressure compelled it, in 1870, to apply to Parliament to be relieved from this obligation, and the relief was given. The District Company, however, had never failed to desire the completion of the Inner Circle, and, as soon as it began to contemplate the prosecution of the undertaking, supported a scheme promoted by an independent company (the Inner Circle Completion Company) for such completion. The independent line (which was authorized in 1874) joined the District line west of Mansion House Station, and passed by way of Cannon Street and Fenchurch Street so as to join the Metropolitan Company's authorized line slightly to the northward of Aldgate Station, which had not then been completed. By this scheme both Mansion House Station and Aldgate Station would have been on what are termed "dead ends." A new street between King William Street and Fenchurch Street was a feature of this undertaking.

The Inner Circle Completion Company, however, failed to raise the necessary capital, and in the meantime the Metropolitan Company had opened its terminal station at Aldgate, and were contemplating further extension southward to Tower Hill.

In 1878 the two Companies agreed to refer the mode of completing the Inner Circle to Sir John Hawkshaw, with the request that he would advise in the interests of all parties.

Sir John Hawkshaw recommended that the circle should be completed by extending the railway southward from Aldgate to Tower Hill and thence westward along Great Tower Street, Eastcheap and Cannon Street to join the District Company's railway at Mansion House, and that advantage should be taken of the prosecution of this work to invite the Corporation of London and the Metropolitan Board of Works to join with the two companies in the construction of a much wanted public improvement, viz., the widening of Eastcheap and Great Tower Street, and the construction of a new street between Mark Lane and Trinity Square.

The Author was appointed, in 1878, joint engineer with Sir John Hawkshaw, and was associated with him in the preparation of the

Parliamentary plans and in carrying the work through to completion.

It was seen that a very important addition could be made to the project by an extension eastward to join the East London Railway, so as to serve the large population of East and South London. Accordingly the Parliamentary plans included not only the completion of the Inner Circle, but also two short junction lines at Aldgate and a railway under the Whitechapel Road, giving both the Metropolitan and District Companies access to the East London Railway and the districts served by it south of the Thames. This extension also placed the systems of the South Eastern, Brighton, and Chatham and Dover Companies in direct communication with the north bank of the Thames, and with the northern Companies which join the Metropolitan Company's system, viz., the Great Northern, Midland, and Great Western Companies.

The eastern extension will not be referred to in detail in this Paper, which is more specially devoted to the Completion of the Inner Circle of the Metropolitan railway system. It need only be remarked, that it has been constructed under the Whitechapel Road and terminates by a junction with the East London Railway, and also by a terminal station (which has been constructed, for the exclusive use of the District Company) on the north side of the Whitechapel Road and adjoining the East London Company's Whitechapel station.

Description of Route.

To return now to the completion of the Inner Circle. The principal line (Railway No. 1 as laid down on the Parliamentary plans), leaves the Mansion House station at its eastern end, and then passes slightly to the southward of and parallel to Great St. Thomas Apostle and Cloak Lane, till it reaches Dowgate Hill, where it bends to the northward under the forecourt of Cannon Street Station, and is continued under the centre of Cannon Street to King William Street. At this point it is bent to the southward to give space for the construction of a station. It is then continued under the widened Eastcheap and Great Tower Street and the new street to Trinity Square, thence passing under the garden of Trinity Square and through some house property it crosses beneath the viaduct of the Blackwall Railway, and turning to the northward is carried under the roadway of the Minories, and joins the southern end of the Aldgate station. The total length is $1\frac{1}{8}$ mile.

Railways Nos. 2 and 3 are respectively the north and south curves connecting Railway No. 1 with the Whitechapel extension line, which is Railway No. 4.

The sharpest curve on the line is 8 chains radius, and the steepest gradient 1 in 100.

It is obvious that the term "Inner Circle" is somewhat of a misnomer. The Metropolitan and District Railways systems form an irregular ellipse rather than a circle, and the eastern portion of the ellipse is so flat that the two lines are approximately parallel and near to each other for some distance. The completion of the ring of railway has been rather the joining together of two parallel lines than the completion of a circle, and this circumstance has no doubt an important bearing on questions of traffic. Although the value of a continuous communication by railway is great, it is considerably depreciated by the long detour which is necessary between Blackfriars on the south and Farringdon Street on the north. The consequence, however, of the extension of the District line to the Tower, and of both lines to Whitechapel and the East London system, is of great value to Londoners, and will be more and more recognised.

Estimate.

The Parliamentary estimate was—

	£.
Railway No. 1, Works	446,941
" " 2, "	46,244
" " 3, "	60,346
" " 4, "	276,789
	830,320
Land	1,534,941
Total	2,365,261

	£.
Street widenings and new street, in addition to the amount included in the estimate of Railway No. 1	929,412

Street Improvements.

The widening of Eastcheap and Great Tower Street, and the construction of the new street formed a very important feature in the enterprise, for it was seen by all parties that the congestion of the traffic in the old streets could not much longer be tolerated. Now that the new street, which is 60 feet wide at its narrowest point, is opened for traffic, it is difficult to believe that so much of the vast

traffic east and west, between London Bridge and the Tower was conducted along the old narrow and tortuous streets. Eastcheap and Tower Street were at their narrowest parts only 25 feet wide, *i.e.*, roadway 15 feet and two pavements of about 5 feet each. It was eminently desirable, in the interests of all parties, that the railway companies and the public authorities should join their forces for the construction of the railway and the streets simultaneously, inasmuch as the burden upon either of the two parties would have been too great for them to face individually.

Lengthy negotiations took place as to the amount which the public bodies should contribute in respect of the improvement, and eventually it was agreed that the Metropolitan Board of Works should contribute £500,000, and the Commissioners of City Sewers £300,000 towards the undertaking. The railway companies undertook the whole responsibility and risk of acquiring the property and constructing the new street and widenings. It may easily be understood that the mode and conditions under which the money was to be provided by the public bodies, gave rise to considerable discussion, and the result was that the year 1882 arrived before the negotiations were complete, and the sanction of Parliament was given to the agreement.

Commencement of Works.

In the meantime the Metropolitan Company, which had already bought land south of Aldgate, was anxious to proceed with the portion of the line from Aldgate to Trinity Square, and it was eventually arranged that it should construct this part of the line without waiting for the completion of the negotiations with the public bodies. Accordingly this portion of the works was commenced in 1881 under Mr. Joseph Tomlinson, Junr., as Engineer to the Metropolitan Company (Mr. T. A. Walker being the Contractor), and was completed as far as the east side of Trinity Square in 1882.

Matters having at length been arranged as to the contributions by the public bodies, the works of the remainder of the undertaking were commenced by Mr. T. A. Walker as Contractor in August 1882, and were completed and opened for traffic (together with the Whitechapel extension) in October 1884. Mr. E. P. Seaton was Resident Engineer, and Mr. J. Wardhaugh, contractor's agent on the Inner Circle railway works. Mr. R. C. H. Davison was Resident Engineer, Mr. L. P. Nott, contractor's agent on the Whitechapel extension.

Setting Out.

The location and setting out of a railway amid such a collection of streets, churches, railway stations, warehouses, shops, and offices, as exists between Mansion House station and the Tower of London, was a matter involving anxious consideration by all, and great care on the part of the executive staff. It was often a question of a few inches whether an important and expensive building could or could not be avoided, the decision involving an expenditure or saving of many thousands of pounds.

The gradients adopted had also to be very carefully considered so as to avoid raising the roadways and streets above the railway, and more interference than was absolutely necessary with the many important sewers which had to pass under the railway.

Sewer Works.

The course of the railway being approximately parallel to the Thames, many sewers draining large areas of London, were of necessity intersected. In all cases the arrangements have been so made that these sewers have been carried under the railway without resorting to inverted siphons; but great alterations of the sewers themselves were necessary in order to enable this to be done.

The first sewer of importance is that in Dowgate Hill, which is 6 feet in internal diameter and often runs full. This sewer had to be lowered almost from its storm outlet into the Thames at Dowgate Dock, and was passed under the railway in two cast-iron pipes 4 feet 6 inches in diameter. From the top of these pipes to the roadway of Dowgate Hill there is only an available space of 19 feet 6 inches for the construction of the railway station.

The next two large sewers which are crossed are the King William Street sewer, 8 feet by 7 feet, and the Gracechurch Street sewer, 8 feet 3 inches by 6 feet 8 inches. These were provided for by partial reconstruction, and by the use of cast-iron horizontal plates for the top of the sewer.

Another sewer running north and south, at Mark Lane, had to be lowered and passed under the railway. This involved the reconstruction of the sewer southward of the line for a considerable distance.

It was also necessary to construct a new sewer on both

sides of the railway throughout its course in Cannon Street, and Great Tower Street, and a portion of Eastcheap. The old sewer, which ran down the middle of the road, was wholly removed to leave room for the railway, but it had to be kept in use, or temporary troughs had to be employed, until the new sewers were finished. Upwards of 300 new connections were made between the drains of the houses and the sewers.

These sewer works, constructed as they were along narrow lanes in the City, with buildings in close juxtaposition, involved much anxious labour, and added greatly to the difficulties of carrying out the railway.

It will also be easily understood that the necessity for temporary accommodation of the sewers and house drains during the construction of the works involved great loss of time, and expense, and much discomfort to all concerned.

The construction of the sewer on each side of the line down Cannon Street, Eastcheap, and Tower Street, involved the works being some 10 feet wider than would have been necessary for the railway alone, and caused them to approach very nearly to the foundations of the important and weighty buildings in those streets. Thus the sewers made necessary what otherwise might have been a matter of doubt, namely, that the houses should be underpinned along almost the whole course of these streets.

Covered Way.

The cross-sections of the covered way for the railway, apart from special construction at particular portions of the line, are shown in Plate 3, Figs. 1, 3, 4 and 9. The high brick arch would have been adopted throughout if the levels of the ground had permitted; but a lower brick arch was necessary between Idol Lane and Seething Lane, and girder construction was required between Queen Street and Dowgate Hill. The arches are made of hard London stocks in Portland cement mortar; the side walls and invert of the covered way of Portland cement concrete. The gravel and sand of the concrete was to a great extent found upon the site of the works, but a considerable portion had to be supplemented by Thames ballast. The ordinary proportions of the cement concrete are as follow:—1 part of Portland cement, 2½ parts of sand, 3½ parts of gravel. The cement was in all cases kept on the Company's property for six weeks, and emptied out of the sacks on dry floors before being used.

Refuges or recesses for the platelayers 4 feet wide and 6 feet high are made in the side walls of the covered way, about every 30 feet on each side of the line.

Some small portions of the line near Minories Junction and near Mansion House Station, are constructed between retaining walls. Plate 4, Fig. 14, shows their construction.

Underpinning Works.

The underpinning of the buildings by the side of the railway is shown in Plate 3, Fig. 8.

The holes excavated beneath the foundations of buildings for the purpose of underpinning were usually about 4 feet long. After the holes had been carried to a good foundation, at least as low as the bottom of the side walls of the covered way, they were filled with Portland cement concrete, and then allowed to stand for thirty-six hours. The top portion was executed in brickwork in Portland cement, very carefully put in so as to ensure com plete tightness below the footings of the old buildings. The works were completely successful, and with one exception there were no cases of any settlement or damage to any of the underpinned buildings.

The case of settlement occurred in a very old house in Cannon Street, and was due to the fact that one end of the front of the house in question was supported on a timber post 9 inches by 3 inches, which was completely rotten at its bottom. This post rested on brickwork which had been successfully underpinned, but owing to some very slight extra pressure put upon the post it gave way suddenly, and there was for a time a risk of the house falling. Such an accident, however, was averted by promptly shoring and supporting the front of the house; but some alarm was created, and the tenants had to leave temporarily. This was the only occurrence of the kind, and it pointed out the necessity in such works, of carefully examining not only the foundations but also the supports of a building above the foundations.

Another interesting work of underpinning was that of the statue of King William IV., which is of massive granite supported upon a granite pillar finely jointed, and resting upon a foundation of lime concrete of rather inferior character. The statue, with its pedestal and foundations, weighs about 160 tons. The construction is shown in Plate 3, Fig. 11.

Previous to underpinning the statue the City authorities took very accurate levels and plumbed the statue, and these levels and plumbings were continued during the progress of the work. Some light timber strutting was erected as a matter of precaution against any damage to the statue itself. The next operation was to sink two holes at the east and west sides of the circular foundation of the statue. These were filled with concrete up to the level of the soffit of the future arch of the railway. Above the level of the soffit the underpinning was continued with brickwork, built in radial courses to suit the rings of the arch of the railway with which this portion of brickwork was intended hereafter to be amalgamated. When the underpinning in the two holes was completed, a short length of 7 feet of the side-wall of the tunnel was constructed, and subsequently further short lengths were put in, making in all a total length on each side of the railway of 30 feet. A heading 4 feet wide was then driven at right angles to the line of the railway through the concrete supporting the foundation of the statue, and in this heading a length of 4 feet of arch was built under the centre of the statue. Subsequently a second heading was driven parallel to the first, and another length of arch turned, a portion of which was the underpinning brickwork which was specially put in for the purpose. When this was finished a third heading was driven and the second underpinning pillar was amalgamated with another length of arching. The fourth heading completed the work under the centre of the statue, and this being finished, the remainder of the arching on both sides was accomplished. When everything had been finished the concrete legs beneath the statue were cut away. Not the smallest subsidence was experienced, and the work is in every way satisfactory.

The side-walls of the tunnel under and adjoining the statue are of brickwork in Portland cement, and the arch consists of four rings of Staffordshire brindle-bricks in cement and seven rings of stocks in cement, the whole backed up with stocks in cement.

Works beneath Buildings.

A work of some interest was the carrying the railway beneath the warehouses on the south side of Great St. Thomas Apostle and Cloak Lane without pulling them down. It was executed as follows (Plate 3, Fig. 2):—The party-walls on each side of the future railway tunnel, and the western part of the front

wall, were underpinned with permanent work, and the eastern portion of the front wall was supported with temporary brick-work, which was carried up high enough to support the stone lintels of the front of the warehouse above its ground-floor level.

The portions of the side walls of the tunnel which passed through the party walls themselves were constructed as under-pinning-work in short lengths of brickwork in cement. When these were completed the intermediate portions of the side walls were undertaken in short lengths and finished up to the level of the springing of the tunnel arch. The portions of the arch of the tunnel between the party-walls were next built and finished with their backing. Each party-wall in turn was then needled on timbers resting on the portions of the completed arches intermediate between the party-walls, and the walls beneath the needles were removed in small pieces to such an extent as would permit of the arch-rings being gradually built in the wall. The arch of the tunnel was thus united beneath the party-walls, and the party-walls were firmly pinned upon the extrados of the arch and backing. When this had been done, the lower parts of the party-walls beneath the soffit of the arch were cut away, the dumpling was removed, and the tunnel completed.

At the eastern portion of the warehouses the roadway of Great St. Thomas Apostle was so low that there was no room for the construction of an arch. In this case girders were inserted instead, the weight of the buildings being borne, during the operation of underpinning, by the temporary piers of brickwork before described, which supported the superstructure while the piers of the building were cut away and the girders were being put in place.

Another work of some little difficulty was the carrying of the railway beneath the old viaduct of the Blackwall railway. In view of a desire of the Great Eastern Railway Company to proceed with the widening of this viaduct in 1880, this work was carried out under a separate contract with Messrs. Lucas and Aird before the remainder of the railway was undertaken. The foundations of the old viaduct were removed and underpinning substituted without in any way disturbing the structure or interfering with the large traffic of the Great Eastern and the Tilbury and Southend railways using the viaduct.

Temporary Works.

A very important part of the work of constructing a railway through the heart of the City of London is that of the temporary works for keeping the street traffic open.

The Act of Parliament contained the following clause:—

"8. In the event of the two companies requiring for the purposes of the Railway or any part of the Railway (subject to the restrictions in this Act contained) to open or in any manner to interfere with the surface of any street or road or of any public footpath then and in that case they shall not proceed so to do unless and until the two Companies shall to the reasonable satisfaction of the chief surveyor or surveyors as the case may be for the district in which such street road or footpath may be situate have provided a temporary bridge or roadway or footpath of a reasonable width, except that for the purpose of providing such temporary bridge roadway or footpath they may open the surface of the street road or footpath between the hours of six p.m. to six a.m. or except only one-half of the surface of such road and one footpath shall be first opened or interfered with leaving the other half of the said street or road and one footpath for the passage of the public until such time as that the half of the said street or road and the footpath first opened or interfered with has been restored to a good and proper state for the safety and convenience of the public and then and not before it shall be lawful for the two Companies temporarily to shut up the other half of the said street or road and to open and interfere with the other footpath but wherever they interfere with or open up any footpath or any portion thereof they shall leave a footpath or provide a temporary footpath of reasonable width and shall also provide or preserve reasonable means of ingress and egress for carriages to and from all courtyards abutting on the footpaths."

The engineers, however, considered that, both from the point of view of the interests of the railway companies as well as from that of the convenience of the public, it was necessary that further accommodation beyond that stipulated in the clause above mentioned should be given while the works were being carried on, and accordingly a clause was inserted in the contract as follows:—

"In constructing the works, the contractor's attention is drawn to the circumstance that the roadway and footpath traffic is not to be interrupted. The contractor will be required, in constructing the Railway along or across streets, and at such other places as the engineers will direct, to provide over the whole site of the covered way a temporary platform, or coverings which will consist of balks of whole timber not less than 12 inches square, laid at distances of not less than 4 feet centre and centre, and covered by two layers of planking, the lower layer not less than 4 inches thick, and the upper layer not less than 3 inches thick. This platform will have to be effectually supported by timber, and effectually maintained, and beneath which the works will have to be carried on."

This arrangement was adhered to throughout the works, and was ingeniously and effectively carried out by the Contractor and the

resident staff. Plate 4, Figs. 18 to 26, will explain the mode in which the timbering was executed in Cannon Street so as to allow space for the works to be constructed, and at the same time accommodate the street traffic.

The first operation was to lay down at night, over such a length of street as could be safely undertaken with a certainty of the operations being finished before 6 o'clock in the morning, the cross-timbers running from one side of the street. These were 12 inches by 12 inches, and placed 4 feet apart from centre to centre, as provided by the contract. Upon them were laid 4-inch planks longitudinally with the roadway, and on the top of these 3-inch planks at right angles to the roadway.

When a sufficient length of this plank roadway had been completed a hoarding was erected upon it about 10 feet wide and about 50 feet long, in which a portable steam-crane was used so as to be able to fill carts at either end of the enclosure.

The next operation was to drive the main heading, and from it cross-headings by which to approach the backs of the cellar walls of the houses. These walls were then broken through, and access was thus obtained to the foundations of the front walls of the buildings without any disturbance of the roadway or foot-pavement. Where there were no cellars the headings were continued up to the front walls, and a side heading was driven parallel to the side of the houses. From the side heading, or else through the cellars, holes (usually about 4 feet long) were then sunk beneath the foundations, and the underpinning concrete and brickwork were placed in position. When this operation was completed the main trenches for the side walls and the sewer were undertaken.

These large trenches, about 9 feet wide, involved very considerable rearrangements of the timbering, in order to support the cellar walls, the roadway, and the gas and water pipes, while leaving a free space for the execution of the trenches. The main trenches were then filled with concrete, the sewers were built, and everything was prepared for the setting of the centres.

This, again, involved new alterations of the timbering to leave a space free for the turning of the arch of the covered way in lengths of 12 feet. When this was done, and the backing put in, the cellar walls were supported.

Brick piers were carried up from the backing to support the large gas and water mains, which during the progress of the excavations had up to this time been propped by temporary expedients on the timbering. The dumpling, or earth included

between the walls and the arch, was then removed, and the invert was inserted in lengths of 12 feet, the walls being well strutted until the invert was hard.

The earth was finally filled in over the arch between the timbers, and was allowed to settle below the timbers and planking for a considerable time, additional earth being added as subsidence took place. At last, when the earth seemed well consolidated, the timbers and planks were removed in lengths and the streets repaved, one-half of the roadway being always available during repaving for the street traffic.

Stations.

The stations between Mansion House and Aldgate are three in number, namely, Cannon Street, Monument, and Mark Lane. A temporary station, called "Tower of London," was built by the Metropolitan Company at the eastern side of Trinity Square, and was used by that Company as a terminal station prior to the opening of the Inner Circle, but, owing to its nearness to Mark Lane Station, it has since been closed. Each station presents distinct features of its own.

Cannon Street Station had to be constructed partly under Dowgate Hill, where there was only 1 foot of available height between the top of the railway and the road, partly under the forecourt of Cannon Street Station and partly under Cannon Street itself. The booking-office had to be accommodated between the top of the railway construction and the surface of the forecourt, and provision had to be made for interchange of traffic with the South-Eastern Company's Cannon Street Terminus. Thus, under the forecourt there are three tiers of traffic, viz., (1) the trains, (2) the passengers using the booking-offices, and (3) the cabs and carriages in the forecourt. Plate 3, Figs. 5, 6, and 7, show the construction at this portion of the station. The total height from the level of the rails to the surface of the forecourt is 25 feet 6 inches, and this small height necessitated the employment of cantilever girders which have only a depth of 2 feet at the centre of their span. The girders are held down on the side walls, and are supported at intermediate situations on the platforms by wrought-iron columns. Longitudinal girders are placed between the cantilever girders, and jack-arches of brickwork are turned between the longitudinal girders.

Ventilating-spaces for Cannon Street Station are provided west

of Dowgate Hill, on the site of the old churchyard of St. John Baptist upon Walbrook, and also on a strip of land adjoining the east side of Dowgate Hill, and by a ventilator on the east side of the forecourt. A transverse underground passage lined with glazed bricks gives access from the booking-office floor to the platforms of the South-Eastern Company's station.

Monument Station is constructed on the site of the old Weigh-House Chapel, and has more area open to the sky than the other stations. It commences at King William Statue and terminates at Pudding Lane. The northern side-wall of the station is so far north of the southern face of Eastcheap that much intricate girder work was required, more especially as it was necessary to provide for carrying a row of buildings on the south side of Eastcheap. The general arrangement is shown in the cross section, Plate 3, Fig. 12. Fish Street Hill and Pudding Lane are carried across the station, the former on girders, and the latter by a brick arch of 52 feet span.

Mark Lane Station is constructed wholly beneath the new street, and is covered by girders in one span of 52 feet, the jack-arches in this case being at right angles to the line of the railway. Where gangways for giving access to the platforms and booking-offices were required, the girders were made deeper, the space between the flanges of the girders being lined with white glazed bricks. Ventilating-spaces are provided on the sides of the line by recessing the walls so as to leave considerable openings; the girders at these points are supported by blue-brick piers or by wrought-iron stanchions (Plate 4, Fig. 17).

The minimum length of the platforms at all the stations is 300 feet, and the minimum width of each platform is 16 feet. The width of the stairs is generally about 8 feet, and the stairs and lobbies are in all cases recessed so as not to encroach on the minimum width of the platforms.

There is nothing peculiar in the arrangement of the station buildings except that they are somewhat more commodious than the older stations. It has been provided that the incoming and outgoing streams of passengers should not be intermingled.

Ventilation.

The ventilation of this portion of the underground railway caused some considerable difficulty. The Act of Parliament gave the companies the right to construct ventilators in the roads and

open spaces, such as those known as "blow-holes"; but when the works were being undertaken, the outcry and agitation against the blow-holes was at its height, and Parliament had gone so far as to take away from the District Company the right to retain some of the blow-holes which it had in a previous session authorized them to construct. The Author does not conceal his preference for blow-holes as an efficient and reasonable mode of ventilating a railway tunnel, and he believes that if they were carried out with a little more consideration for artistic effect, and not carried up quite so high as those which were at first constructed, they are the least objectionable means, as they certainly are the most efficient, of ventilating an underground railway. The agitation against their use was, however, so great in 1883, that the Joint-Committee of the two Companies shrank from encountering another storm, and the City authorities and the Metropolitan Board of Works strongly urged that no blow-holes should be made; indeed, the latter body went so far as to say that if any opening were made in the new street, they would not grant their contribution of £500,000 towards the improvement. The result was that it were decided to adopt the alternative which had been pressed upon the District Company by the public authorities, namely, putting up fans to exhaust the foul air from the tunnel by machinery.

Accordingly, fans have been erected, one in Cannon Street, midway between Cannon Street and Monument Stations, another midway between Monument and Mark Lane, and one in the Whitechapel Road. The Cannon Street and Whitechapel fans have a diameter of 18 feet, with a width of 4 feet, and the Tower Street fan a diameter of 15 feet, and a width of 5 feet 6 inches. Gas-engines of 12-HP. were employed to drive the fans, and the fans when driven at sixty revolutions a minute, expelled about 70,000 cubic feet per minute from a shaft, the top of which was at least as high as the adjoining buildings. The general arrangement is shown in Plate 3, Fig. 10, and Plate 4, Fig. 15. The fans had no sooner been set to work than complaints began to arrive of the vibration which was set up. The subject being inquired into, it was found that the vibration complained of was due, not to any defect in the engines or fans, but to the undulatory motion imparted to the air by the fan itself. Some of the inhabitants of Cannon Street and Tower Street applied to the Court of Chancery for an injunction to restrain the Companies from using the fans, and the injunction was granted.

It may be interesting to compare the work of one of the fans

with the work performed by the blow-holes. The following Table gives the amount of air expelled and indrawn at the various blow-holes which were erected upon the District Railway in 1883:—

Ventilator.	In-draught per hour, Cubic Feet.	Out-draught per hour, Cubic Feet.
No. 1 . .	1,813,500	1,156,080
" 2* . .	797,040	616,800
" 3* . .	1,672,080	1,065,000
" 4* . .	2,448,300	1,285,560
" 5* . .	1,381,680	1,096,020
" 6* . .	1,976,520	2,592,720
" 7 . .	1,219,200	967,200
" 8 . .	1,359,000	1,782,480
" 9 . .	718,200	569,880
" 10* . .	284,280	3,459,240
	13,669,800	14,590,980

Those marked * are the result of actual quantitative measurements, the remainder are deduced from these.

In the case of ventilating by blow-holes, the air drawn in and expelled at the tunnel-fronts has either to be taken into account in arriving at the total ventilation of a length of railway, or else in the ordinary case on the District Line of there being two blow-holes between each station, the indraught and outdraught of air at the two blow-holes have to be added together in order to arrive approximately at their effect.

It will be seen that the work performed by the fan, at a very considerable expenditure of engine-power, amounts to much the same as what is effected by one blow-hole, such as that in Queen Victoria Street or near Victoria Station. In the case of the blow-holes the power is provided by the induced current due to the passage of the trains, and thus each hole acts as a lung or gill, working rateably with the number of trains travelling on and fouling the railway. Thus the same agency which fouls the air of a tunnel by the passage of an engine, supplies the power for purifying the air. The Companies are now undertaking experiments to endeavour to obviate, or at any rate to reduce, the vibratory motion of the air near the fans.

Traffic.

The Author does not propose to enter on the subject of the value of the traffic of the Inner Circle line, further than to say that up to this time it has been financially disappointing. No

doubt it has not at present been fully developed, and though perhaps the value of the circular working has been over-estimated, it is probable that the east and west traffic may become yearly of more importance. It may be interesting to state what the present train-service is.

There are on each line of way, during the working hours of the day, the following number of trains per hour between Mansion House Station and the Minories Junction, which is the point south of Aldgate Station at which the Whitechapel extension joins the Inner Circle line:—

Eight Inner Circle trains, running every seven and a half minutes completely round the circle, by way of Aldgate, King's Cross, Paddington, High Street, South Kensington, Westminster, and Mansion House. Six District Company's trains from Ealing, Richmond, and Fulham, by way of Earl's Court, South Kensington, and Mansion House to Whitechapel or (*vià* the Thames Tunnel) to New Cross—Total, fourteen per hour.

Between South Kensington and Mansion House there are, in addition to the above, two trains per hour on the Middle Circle, running from Aldgate by King's Cross, Bishop's Road, Addison Road, and Earl's Court; and two trains per hour on the Outer Circle, running from Broad Street (L. and N. W.) by Dalston, Camden Town, Hampstead, Willesden, Addison Road, and Earl's Court. Thus between Mansion House and South Kensington there are eighteen trains per hour on each line.

The Metropolitan Company works a service of two trains per hour in each direction between Aldgate and Whitechapel, and under the river to New Cross.

On the Metropolitan line, between Moorgate and Edgware Road, there are in the busiest hours of the day eleven trains per hour, in addition to the eight Inner Circle trains, and thus there are at those times nineteen trains per hour on this part of the Metropolitan Company's system. These trains are exclusive of those which use the two lines on the Metropolitan Railway between Moorgate and King's Cross, which are devoted to the traffic of foreign companies working over this part of the Metropolitan system.

Conclusion.

The execution of the works was greatly facilitated by the support and assistance given by the Metropolitan Board of Works, the City Commissioners of Sewers, and by their engineers, Sir

J. W. Bazalgette, C.B., Past-President, and Mr. W. Haywood, M. Inst. C.E., and by the way in which the latter body met the requirements of the Companies as to the conduct of the traffic of the streets. The Author ventures to hope that the confidence which was thus given to those in charge of the undertaking has not been considered, by the City Commissioners of Sewers, to have been misplaced. It was the anxious desire of all concerned to cause as little inconvenience as possible to the important interests of the public using the streets traversed by the new railway.

The whole cost has amounted to about £20,000 less than the Parliamentary estimate of the works, and the cost of the land was also less than was estimated.

It is gratifying to be able to remark that no serious accident occurred in the carrying through of the enterprise.

The work was prosecuted with great energy and fertility of resource by the contractor; the average number of men employed when the works were in active operation was about 850 by day and 500 by night.

Considering the intricate nature of the work, and the many interests involved, the time occupied in their execution, namely, two years, was not great. Much of the work had of necessity to be undertaken in successive stages, one portion having to wait for the completion of the other.

The Paper is accompanied by numerous drawings from which Plates 3 and 4 have been engraved.

[DISCUSSION.

Discussion.

Mr. Barry. Mr. Barry said he had brought with him a model in sections showing the way in which the timbering was put together in Cannon Street, and the order in which the works were executed. It first showed the street before anything was done with the sewer running down the middle of the street, and also the gas and waterpipes. The first operation was to lay down timbers right across the street; then the ground was taken away from under the timbers, and the first heading was driven longitudinally with the railway; from this heading side headings were driven towards the front of the houses. The next section of the model showed the side headings by which the fronts of the houses were approached, either through the walls of the cellar, or through the ground. From those side headings, underpinning holes were sunk under the foundations of the houses and filled in with concrete in regular rotation one after the other, but never touching each other until the closing length was put in. When the underpinning had reached a forward state, the main trenches shown in the third section of the model were undertaken for the construction of the wall and the new sewers, the old sewer, through the middle of the dumpling being still retained. The side-walls having been built, the next stage shown by the model was the setting of the centres preparatory to the turning of the arch. It would, of course, be understood that when the centres were set the work involved a great reconstruction of the timbering in order to carry it over the space left for the turning of the arch. Finally, the gas- and waterpipes were supported on brick piers resting on the top of the arch. The completed works were shown on the last section of the model. The model in fact was another mode of explaining the various stages of the works illustrated in Plate 4, Figs. 18 to 26.

Mr. Tomlinson. Mr. Joseph Tomlinson said in describing the works of the Metropolitan and Metropolitan District Railways, the Authors had referred to those portions that came under their immediate supervision; but that part of the line from Moorgate Street to Mark Lane Station, including the temporary station at Trinity Square, called the "Tower of London," had not been referred to, and he thought it would be interesting if he laid that portion of the line before the meeting. In constructing the portion of the Metropolitan Extension from Moorgate Street to Bishopsgate, the late Mr. E. Wilson, M. Inst. C.E., encountered little or no difficulty, except where the line passed between the Roman Catholic

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Church of St. Mary, and the Nonconformist Chapel in Blomfield Street. The former was built on piles, in the peat formation, and all the four walls had to be underpinned, to a depth exceeding 30 feet, causing the removal of the remains of those buried there. The coffins, on the completion of the work, were replaced, and the vaults bricked up. Great care, also, had to be exercised to prevent damage to the altar-panelling, on fresco on the east wall, about which much anxiety was felt; but no damage beyond one or two very slight cracks took place, and it was now as perfect as when first painted. All the columns supporting the roof had also to be underpinned to the depth of the outer walls. The portion of the work from Bishopsgate to Aldgate had been executed by Mr. F. Brady, M. Inst. C.E., as stated, but no difficulties of any moment were experienced until excavating for the Aldgate Station, where, after removing the made ground to a depth of about 14 feet, large quantities of water were met with, involving very powerful pumping-plant. It was thought at the time that this water could be utilized as it appeared to be inexhaustible; but on analysis it was found to be of the very worst description, being unfit for engine- or domestic use, though as clean and sparkling as any mountain stream.

The part of the line constructed by himself was from Aldgate High Street to the western side of Trinity Square. The works in the Minories formed a most marked feature, and added greatly to the successful way in which the City lines were constructed down the more crowded and important thoroughfares of Cannon Street and Eastcheap, the same clauses in the Act of Parliament, relating to keeping open the streets from 6 A.M. to 6 P.M. having to be observed. The first piece of the temporary bridging was laid here. The first thing that had to be ascertained was the length of road that could be taken up, and the number of timber balks laid down and covered with the plank road within that time. The workmen had also to be trained, and the work organized. The first night only two timbers, or 8 feet of road, were put in, and it was with the utmost difficulty that the road could be made good within the specified time. The next night two were put in much quicker, and as the men became drilled to the process, as many as five were placed and covered with the roadway planks in one night. The next thing to consider was the way to support the timbers during the construction of the side walls. Raking struts were at first employed, but as these involved a great waste of timber, and much labour, straight props and horseheads were substituted, and it was

Mr. Tomlinson. found that this was the best method to be adopted. He would also like to draw attention to the section of covered way between Aldgate and Tower Hill, Plate 4, Fig. 13; and at Chequer's Yard, shown in Plate 4, Fig. 14, which was of the same character, as was afterwards adopted by Sir John Hawkshaw and Mr. Barry, as it stood well, and was less costly than the covered way they had originally intended.

A work of a most dangerous and difficult nature, was the construction of the railway under Aldgate High Street. The northern portion of the bridge formed a part of Aldgate station, and under the roadway there were three of the largest gas-mains in London, two being 36 inches in diameter and one 24 inches, under a very high pressure. Upon stripping these mains they were found to be in the most irregular lines, and badly laid. This involved great expense and loss of time, as they had to be straightened before any work could be done. The method of carrying the mains was by placing wrought-iron plate girders on each side of them. The girders were in three spans, supported on the side wall at each end, and on cast-iron columns. Upon the bottom flange of these, cross-girders were riveted, and on the top of the cross-girders, wrought-iron floor-plates were put in. While the girders were being fixed the mains were supported on trestles. These remained in until some of the floor-plates were in position, and then timbers hollowed out so as to fit the mains were placed under them, and tightly wedged up from the plates; as soon as this was done the remaining plates were put in, and the whole space between the girders and pipes was filled with concrete and asphalted.

During the progress of these works, the pipes were fully charged with gas, and it was satisfactory to state that there had been no escape of gas, or the slightest damage done to any of the pipes. The water-mains were treated in the same manner. On the south side of Aldgate High Street, girders had been fixed, so as to enable the companies to rebuild the houses. One of the most interesting pieces of work, was that of passing through the ditch surrounding the London Wall. In crossing this at the Crescent, the form of arch used was shown in Plate 3, Fig. 9. The ditch was filled in about two hundred and fifty years ago evidently with the refuse of the City, and was very full of water. The line was constructed through the houses in the Crescent. These were of three storeys, and had previously settled considerably. The builders had apparently anticipated this, as they were all tied together with bolts and large timbers. Owing to

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their shattered condition, it was deemed advisable to construct the covered way before taking them down. They were therefore shored up, and stretchers were put in between the houses. The side-walls, in short lengths, were then put in as quickly as possible, so as to drain as little water as could be from the ditch. The spaces between the party-walls of the houses and the side walls of the railway were filled with concrete, and upon this a new facing wall was built, and well bonded to the party-walls. When this was well set the front walls of the houses were removed. The temporary station at the Tower consisted of a wooden booking-office at the road-level, carried on girders sufficiently strong to allow of buildings to be hereafter erected upon them, and platforms 12 feet wide and 300 feet long, covered with a light cantilever wooden roof. The line was carried to the western side of Trinity Square gardens, and ventilated by an opening in the tunnel 7 feet square. This short piece of line from the station afforded every accommodation for shunting.

On the opening of Aldgate Station, the Commissioners of Sewers refused to allow the hot water emptied from the condensing-tanks from the engines to be conveyed down their sewers, and it became necessary to construct a pipe directly to the River Thames.

These City lines were at that time in contemplation, and as the carrying of them out would involve the re-construction of the old sewer running down the centre of the Minories, at a much lower level, he thought it expedient to alter the level of the sewer at the same time that the pipe was laid. A sewer was therefore constructed, 5 feet by 3 feet of stock brickwork in cement, from Aldgate to the Irongate sewer, at the southern end of the Minories. Eyes for the house connections were left in the sewer; but it was not until the works of the railway were in progress that these connections were made. By making this sewer the ground was thoroughly drained, and no further trouble from water was encountered. Another alteration was necessary to the sewer running down Aldgate, which had to be lowered for a considerable distance. This alteration enabled the north and south curves joining the Whitechapel line to be put in without further difficulty, only the house connections having to be made. It was carried under the side walls of the railway by relieving arches, and the sides and arches of the sewer were thickened under the rails. Running under the centre of the London ditch was the old Irongate sewer, 6 feet by 3 feet. This was intercepted and carried to a lower level by means of a tumbling bay under the railway, and under Hammet Street, forming a connection with the Minories sewer. This involved a

Mr. Tomlinson. diversion of 80 yards. All the side sewers that were met with had to be dealt with as those in Cannon Street, already described. Unfortunately for the companies, they were very numerous, and all had to be connected by stairs or tumbling bays.

Mr. Fox. Mr. C. Douglas Fox observed, that although Mr. Baker had described a work carried out many years ago, he was sure all the members must feel that this work had effected a complete revolution in the ideas of engineers with reference to construction, and also had shown them how to deal effectively with the special difficulties always encountered in a large city. Those who had carefully watched the progress of the Metropolitan and the Metropolitan District Railways must have learned many an instructive lesson. The underpinning carried out in Cannon Street was, without exception, superior to anything of the kind ever before attempted. It was carried out under a main thoroughfare crowded with traffic, in very treacherous soil, in the midst of sewers, which had been described by Mr. Tomlinson as the chief enemy of the underground worker, and the work had been completed absolutely without accident. He wished to ask whether the pumping, which was permanently necessary in connection with the Metropolitan District Railway, had led to any difficulties from the absorption of the ballast and the choking of the pumps, as he had met with hindrances of that nature in a railway with which he was connected. He also would be glad to know whether in dealing with treacherous ground, the amount of subsidence was diminished or otherwise by leaving in the crown bars over the tunnel, and by building up between the crown bars with brickwork in cement, so as to prevent a future subsidence when the crown bars themselves decayed. The ventilation of the Underground Railway certainly required improvement, and he thought it could be improved. He was quite sure that if those who had exercised such skill in the construction of the line, would only direct their minds earnestly to that question, a revolution might be effected in the condition of the underground atmosphere. He should be glad to know what had been the effect of the fans on the Inner Circle link while they were working. They were of comparatively small size, and perhaps Mr. Barry would state why that size had been adopted instead of a larger size running at a lower speed. One thing that appeared very distinctly from the Papers, was the great importance in that kind of construction of a thoroughly good invert. It accorded with his own experience, as he had found that a great deal might be saved in other parts of the construction by taking care to hold the toe

of the wall firmly by a thoroughly substantial invert, and, in the present days of concrete, that could be done at a moderate cost, without fear of the toe of the wall moving in, as had been the case in several instances. Mr. Fox.

Mr. G. WELLS OWEN said it was one of the peculiarities of Papers like those which had been read, that, whilst containing most valuable information, interesting to all engineers and valuable for purposes of reference in the records of the Institution, they nevertheless presented very few subjects for discussion, unless indeed the works were those which might be called "awful examples," in which case, of course, they would not be described. His only object in rising was to ask a few questions upon matters which he thought were of general interest. Mr. Baker had stated that the Campden Hill tunnel arch was in gravel, sand and brick-earth, but that the London Clay rose at places within 6 feet of the top of the brickwork. There was no section of the tunnel amongst the diagrams, and he should be glad if such a section could be given, because it was well known that difficulties had been experienced in London Clay on the southern side of London, especially in the Sydenham Hill tunnel, where the section had to be made of a circular form, and where, when the engineers tried to make it originally of a different section, great difficulties had been met with. At Campden Hill, no doubt, the clay was not of the same character as that on the southern side of the Thames; he presumed that it was blue, and not yellow clay; still he thought that a few words from Mr. Baker as to the section adopted would be of interest to the members. He also wished to ask the Authors what live-load had been adopted per square foot of roadway for over-bridges, or in cases where the railway went under roads. Engineers formerly used to take 120 lbs. per square foot as being the weight of a crowd, but in the present days of traction-engines in the country, and of steam-rollers in London, he had adopted for several years past a constant of 2 cwt. to the square foot. He observed that the price of concrete had been stated by Mr. Baker be 7*s.* 6*d.* per cubic yard. That was a low price for concrete, but he presumed that in that case the gravel was found upon the spot, so that there would be no cost in obtaining it. Mr. Baker had stated, "It is known now what precautions are necessary to ensure the safety of valuable buildings near to the excavations; how to timber the cuttings securely, and keep them clear of water without drawing the sand from under the foundations of adjoining houses." It would be very interesting if the Author would enlarge a little upon that point, especially in regard to not "drawing the sand from Mr. Owen.

Mr. Owen. under the foundations of adjoining houses." In describing the permanent way upon the Metropolitan Railway, Mr. Baker had stated that the flange rail was used until 1873, when it was gradually replaced by a chair road, but he had not given the particulars of the permanent way now used. Mr. Owen had recently been constructing the Hounslow and Metropolitan Railway, a line worked by the District Company, and their latest extension westward, and he had adopted the present standard permanent way of the District Railway, which was one of the heaviest permanent ways in the world. It was a bull-head steel rail of 87 lbs., with a chair of 47 lbs. and a cross-sleeper 12 inches by 6 inches. Perhaps Mr. Tomlinson would state whether the same kind of permanent way was now used upon the Metropolitan line.

Mr. Tomlinson. Mr. TOMLINSON said it was the permanent way that he had adopted in 1874, doing away with the Vignoles rail, and afterwards adopted by the District Company; but the Metropolitan Company now went even further, putting points and crossings on timbers, 14 inches by 7 inches spaced 2 feet apart. The main line sleepers were placed at intervals of 2 feet 8 inches from centre to centre. The chair was not so heavy as that of the District Company, being only 39 lbs., but he thought that was quite heavy enough.

Mr. Lewis. Mr. W. B. LEWIS observed that it had been stated by Mr. Barry that the Metropolitan lines constructed by him were carried out for £20,000 under the estimate. He was surprised that any one could estimate such a work so nearly. Perhaps Mr. Barry could give some information as to the cost of underpinning per lineal yard.

Capt. Galton. Captain DOUGLAS GALTON thought that there could be no doubt that the simplest and most efficient way of ventilating a tube a little below the surface of the ground, in which trains were run, was by means of openings at intervals. If fans were adopted a considerable amount of power would have to be expended, whereas by means of these openings power was supplied for ventilating purposes by the movements of the trains themselves; because the train acted as a piston, and drove out the air before it, and also sucked in fresh air when the train had passed the opening. He thought if the tube could be divided into two parts, one part for the up and one for the down trains, there would be no difficulty in ventilating the line. Of course with a railway like the Metropolitan District Railway, in which the tube was not divided, and the trains were running in opposite directions at frequent intervals, and the trains filled only a very limited part of the area,

Capt. Galton.

the currents of air were very much disturbed, and the same beneficial effect was not obtained from the action of a train as a piston. The complete action could be obtained if there were two tubes, one tube for the up and one for the down line. But in any case, under the conditions of the Metropolitan District Railway, blow-holes were certainly the most economical arrangement for obtaining an adequate degree of ventilation. There were plenty of cases in which ventilation was obtained by fans, and perhaps the most notable was that at the Edgehill tunnel, near Liverpool. In that tunnel the air was kept fresh by the action of the fan in the centre of the tunnel; and a story he had once heard illustrated the force of suction of this fan. An engine-driver had been furnished, one Saturday evening too late for post, with a letter to take to Edge-hill, to be given to the guard of a late train for conveyance to London, as it was of the utmost importance that it should be delivered at Euston on Monday morning. The driver happened to pull out his pocket-handkerchief as he was going along the tunnel, and the up-draught of the fan carried the letter away, and it was lost. It was, however, delivered in London by post on Monday morning, the probability being that some one had picked it up at the top of the tunnel and posted it. He had not had the opportunity of seeing any of the experiments made with the fan at Cannon Street. He would wish to see experiments made especially with reference to the degree of resistance from suction against the fan, and of the assistance to the exit of the air caused by the passage of the trains as they approached and passed the place where the extraction of air took place.

Mr. Galbraith.

Mr. W. R. Galbraith thought that one or two points had been pretty well settled by the Papers in reference to the construction of underground railways in London. The first was with regard to excavation. The first underground railway was commenced by excavating to the full width, and by a good deal of heavy timbering, the result being, as Mr. Baker had stated, a considerable cracking of the ground adjacent to the timbering. It seemed that the right way of constructing tunnels or covered ways was by putting in side walls in a narrow trench, leaving a dumpling in, and removing it afterwards. All later experience had shown that if engineers and contractors had attempted to take out the ground to the full width of the railway in the City, in the midst of all the heavy buildings, some serious accidents would have happened; at least, there would have been a very great destruction of property. He had been struck with some of the prices mentioned in Mr. Baker's Paper. Where the excavation was taken out to the full width, in

Mr. Galbraith. some places in heavy ground, the work including the timbering but not including the carting away, was done for about 1s. 0½d. per cubic yard. He did not know what Mr. Baker's experience had been since, but from what Mr. Galbraith knew of contractors at the present time, he thought some of them would stare if they were asked to take out excavations, with a great deal of timbering, at that price. The tunnel brickwork, which he supposed included centres partly of gravel and partly of London Clay, was put at 30s. per cubic yard, which seemed a very moderate amount. He should be glad to know from Mr. Barry if the work in later years had been as economical as it appeared to have been twenty-five or thirty years ago. With reference to the settlement of buildings, he did not know whether any members had noticed the construction of the new tunnel of the London and North-Western Railway Company at Primrose Hill. He had not been in the tunnel during its construction, but it did not seem to have been carried out with as little disturbance to buildings as had been achieved in the Underground Railway. From end to end all the buildings were cracked in the neighbourhood of the tunnel, and the company must have paid a large amount for compensation. With reference to the question of permanent-way, theoretically, the direct fastening of the flanged rail to the sleeper appeared to be right; but permanent-way engineers, who had to maintain railways, seemed always to discard it, and for heavy traffic and high speed to come back to the double-headed rail and the chair and sleeper, which had been found to be the best form of road for the purpose. In regard to the ironwork on the Inner Circle completion, there was certainly no error on the side of lightness. Iron was cheap, and Mr. Barry had taken the precaution of making it of ample strength; indeed, some of the flanges of the girders were so thick that one might well wonder whether the riveting could act with proper effect through such an enormous mass. On the subject of ventilation, he certainly, as one of the public, sympathised with the objection to the blow-holes in the streets. He thought that the Metropolitan Companies, who had used the streets, were bound to do something for the accommodation of the public, and not turn out the steam in the centre of the streets. The principal objection had been to the blow-holes in the Thames Embankment Gardens; but his impression was that there it was not the slightest offence to any one, and that the objection was purely sentimental. The great erections in the centre of the streets, however, were a nuisance, and a constant source of danger, and the railway companies had been rightly asked—even at some

little extra expense—to ventilate their tunnels in some other way. An accident might easily arise when driving a spirited horse past a place where a jet of steam was suddenly emitted. He felt strongly that the extensions from the circle ought not to have been permitted to such a degree. The Metropolitan Railway proper ought rather to have been looked upon as a circular railway, with frequent service trains running round in the circle, with branches where passengers could interchange, as in the case of the St. John's Wood line. At present two companies were working over the Whitechapel line, the District Company being chiefly interested in the Southern line, and the Metropolitan in the Northern. One stream from Whitechapel passed to the south and another to the north, and the result was that there was no great addition to the train service on the circular system. A person at Cannon Street wanting to go to Bishopsgate Street did not gain much by the construction of the railway. He thought that the two companies had rather spoiled the object of the lines by competing for outside traffic running over their own portion of the railway instead of working it as a circular railway with branches coming up to it, and allowing passengers to interchange. He could not think that it was ever the intention that the Metropolitan Railway should be extended to Birmingham, or the District Railway to Portsmouth. Mr. Galbraith.

Mr. J. H. Greathead said that he had lately had occasion to inquire into the working of the trains on the Metropolitan Railway, and he was astonished to find how large a portion of the locomotive-power on the railway was wasted. The proportion actually employed in carrying passengers, that was the live-load, appeared to be something like 2 per cent. Considering how very difficult it was to ventilate the railway when worked by locomotives, and how disadvantageously it was worked in regard to useful effect, he thought the time had come when some enquiry should be made as to whether it was not possible to work the railway by some of the other methods available at the present time. He had been recently inquiring into the question of the employment of the cable-system, and he believed it might be well employed in taking trains much more frequently than they were taken on the Underground Railways at the same speed, and at something like half the cost. Mr. Greathead.

Mr. T. R. Crampton thought the permanent way of long tunnels, or series of tunnels, involving considerable expense in maintenance, and danger to the men effecting repairs, might, where it was possible to form a perfectly solid foundation, be built up Mr. Crampton.

Mr. Crampton. forming part of the invert. A thin sheet of elastic material should be placed on the foundation on which the longitudinal sleepers should rest, the whole being secured by bolts and nuts entirely exposed to view, and readily screwed up on any movement of sleepers being discovered. The elastic material would make a perfect fit and prevent abrasion, the internal elasticity of the sleeper being sufficient to prevent jars. The effect would be similar to a longitudinal resting on iron girders of viaducts. Rigid foundations had hitherto failed through movement taking place in the structure. The culverts or drains would be open, placed between the rails or intermediate space. Of course, the system at certain points might have to be varied to suit circumstances, which would not involve much ingenuity to arrange for.

Mr. Woods. Mr. E. Woods, Vice-President, remarked that engineers had long since abandoned the idea of placing rails upon a solid foundation. When the Liverpool and Manchester Railway was first made, Mr. George Stephenson entertained that idea, and in the Olive Mount cutting he laid chairs and rails on the solid rock. The result was that the rails were very soon broken and bent, and had to be taken up, and the rock had to be excavated to a proper depth to allow ballast being laid down and the road made elastic. When the Manchester and Bolton Railway was made, Mr. Jesse Hartley, then the engineer to the Liverpool Dock Estate, who had great faith in solid masonry, and to whom the engineering of that line had been entrusted, thought that a rigid foundation was the best for permanent way, and he accordingly laid the rails on solid stone walls, the result being that the whole had to be taken up and relaid. A great portion of the Liverpool and Manchester Railway, in all the cuttings whether of clay or rock, was originally laid upon stone blocks; sleepers were only used on the embankments in order to facilitate the repairs of the road and the raising of the road when the embankments settled. But when the Grand Junction Railway was made, Mr. Locke adopted sleepers over the whole line, and that system, he believed, had been almost universal ever since. It appeared now to be the recognized practice of engineers to lay the road upon an elastic foundation of timber on ballast, and he could not agree that the method suggested by Mr. Crampton would be superior to that used on the District Railways, namely, laying double-headed rails of a very heavy section upon sleepers. He could not sit down without offering his tribute of admiration for the excellent Papers that had been read. Those who had made tunnels under towns would be well able to appreciate the value

of such a record. He had himself had occasion to make a long tunnel under Liverpool many years ago, when he experienced some serious difficulties, but nothing like those which had been encountered by the Metropolitan lines. He had been interested in seeing the works carried on in Cannon Street, and he thought that every one who had had an opportunity of examining them must have been impressed with the great amount of talent displayed in their design. Mr. Woods.

Mr. Baker, in reply said, Mr. Fox had spoken of the expediency of building in crown bars. That precaution was invariably taken wherever the tunnels passed near buildings. The Campden Hill tunnel had been described in the Paper, and any one could sketch it from the description there given. It had a semi-circular top, six or seven rings thick, and the springing was 5 feet 6 inches above rail level. He had not thought it necessary to encumber the walls with diagrams representing it. In regard to the precautions taken in going past buildings to avoid drawing sand with the water from under the foundations, the usual course adopted was to sink a sump and drain the ground before commencing the main excavations. The sump, generally 9 feet in diameter, was a cast-iron tube, or sometimes of wrought-iron. If it was sunk below the foundation, and the pumping was started some time in advance, it was perfectly practicable to make the excavation of the trenches without any risk of drawing sand from under the buildings. As to the other precautions dictated by experience, one of them had been already referred to—the abandonment of the plan of timbering across the entire excavation, which was the primitive form of carrying out the railway. Where traffic had to be maintained overhead, timber had been laid the whole way across, and the roadway carried on balks, as described by Mr. Barry in the case of Cannon Street. This had been done on the Metropolitan Railway twenty-two years ago as shown on Plate 1, Fig. 6. As he had stated in his Paper, it was not practicable in heavy ground to timber the whole width, because of the danger of cracking adjoining buildings. The contractors had been taught by experience to put the side walls in trenches, and remove the dumpling afterwards. If they wanted to be particularly cautious in passing the corner of a building, they executed the side walls in short lengths of 12 feet, or sometimes as little as 4 feet. In that way they passed buildings of very great age and weight, and with very imperfect foundations, without any underpinning at all. An example of that mode of construction would be seen in Plate 2, Fig. 20. On the left-hand side was a building Mr. Baker.

Mr. Baker. 80 feet in height, belonging to the Bible Society, and on the right hand side was another building more than one hundred years old. The railway was carried between those buildings, and with the low-level sewer underneath, without underpinning at all, by carrying out the work in short lengths. Another very novel piece of work, perhaps the most difficult in the whole line was the "widening" tunnel in Ray Street (Plate 2, Fig. 23). Through the old Metropolitan tunnel, trains were thundering every three minutes. While that traffic was maintained they had to drive the "widening" tunnel at a lower level, and it was executed without the slightest crack or injury to the old one; indeed no one travelling on the line knew that any works were going on. The cost of underpinning the Ray Street bridge at this point, was about 12*s.* 6*d.* per cubic yard for excavation, and for brickwork about £2 per yard. With reference to ventilation, of course the advantage of blow-holes had been long known. The first ones had been constructed by Mr. Fowler in 1871 in the Euston Road, but the suggestion was made as long ago as 1845 by the City Architect. As to the question of inverts, he agreed with Mr. Fox, that it was an effectual remedy for sliding at the toe; but he did not think it followed that inverts should be adopted without exception in such works as the Metropolitan Railway. A present expenditure of say £100,000 to guard against a possible future liability of £10,000, would be too heavy a rate of insurance to be justified.

Mr. Barry. Mr. Barry, in reply, said that Mr. Fox had asked what had been done with the water. Fortunately, in the City lines extensions, as almost the whole of the work was above the main low-level sewer, there was not much water, and therefore no trouble was experienced from drawing sand from under buildings. In those few cases the plan mentioned by Mr. Baker of putting a sump some considerable distance from the buildings, and letting the water flow quietly to the sump from which it was pumped, was adopted. No doubt pumping near buildings was a dangerous thing, and frequently produced some settlement. With reference to the elliptical arch, which was employed in the part of the line first executed near the Blackwall viaduct, it was certainly in the quantity of material required, rather a cheaper section; that was to say, a thinner side wall could be made than with a segmental arch and straight walls. But in dealing with the difficulties of putting in walls among the intricacies of the timber in Metropolitan Railways, it was found to be a great advantage to have an upright side-wall. It was difficult

to set the moulds accurately for putting concrete into elliptical side walls, and the straight side walls were therefore adopted with much advantage. There were not any crown bars, as all the work was done, as it were, in open cutting. No doubt crown-bars of tunnels ought to be built in with brickwork in any dangerous ground, and the small expense of the extra brickwork would be amply repaid. With reference to ventilation, in this case where small pieces of expensive property were alone available for ventilating stations, the use of fans of rather small diameter and breast was obligatory, and some amount of difficulty arose from the speed at which they were driven. No doubt, with a larger fan and a larger breast, the work might have been done at a less speed, and there might not have been so much difficulty with the vibration. Since the reading of the Paper, however, the experiments alluded to in it had been made, and he expected some improvement in regard to the vibration. The fan when first started seemed to work so very smoothly and quietly that it was difficult to believe that vibration was being experienced in the neighbourhood; it was not perceptible without going into the adjoining houses, where it was found that the loose-fitting window sashes were most efficient vibration-meters. It was singular that a fan, which, when working in the open appeared to be so quiet a machine, was found, when set to work in towns, to produce very great inconveniences, making the windows shake for a radius of 50 or 60 yards all round. Injunctions in Chancery had been consequently obtained, restraining their use. Whether the difficulties complained of would be overcome he could not say, but Mr. Tomlinson and himself were trying their best to remove them. One experiment it might be interesting to mention. Mr. Walker, the maker of the fan, had made some experiments in Lancashire with orifices of different shapes, and he had recently written to say that he fully hoped that he had arrived at some very great improvements. One of those improvements had been tried experimentally, and, as far as Mr. Barry could judge, it promised well. Instead of having a rectangular orifice for the discharge of the air it was made much larger and triangular. By its use the vibration had been diminished by at least one-half, and he hoped that it might be still further reduced. The work of the fan, as to which a question had been asked by Captain Galton, was something like the work of one blow-hole, and many of the neighbours who had been asked whether they would prefer a blow-hole or a fan, replied, "Give us the blow-hole." He was bound to say that the inconvenience of blow-holes had Mr. Barry.

Mr. Barry. been grossly exaggerated. On the Thames Embankment it was nonsense to say that they did harm to anybody. It had been stated that the air from the tunnel would kill the trees and shrubs. It had certainly not killed the ivy round the blow-holes, where it was growing as he had never seen ivy grow before. As to the inconvenience to the traffic due to the blow-holes, when the matter was carefully investigated by antagonists to them, only one or two instances of danger or accident could be cited over a period of ten years. When the great advantage of blow-holes was considered, and compared with the small amount of inconvenience occasioned by them, the case made out for them was exceedingly strong. As to the size of sleepers on underground railways, sleepers 12 inches by 6 feet were, in the long run, the most economical. The solidity of the road and the duration of life of the sleepers were so great that they amply repaid the first extra cost occasioned by them. Mr. Lewis had expressed some surprise that so close an estimate of the cost of the work had been made. Sir John Hawkshaw and he had had some little experience in such matters, and before making their Parliamentary estimate they had decided to take very liberal prices before pledging themselves to Parliament. They had thought at one time that they might be able to do the work for much less than the Parliamentary estimate, but in this they had been disappointed. With reference to the cost of underpinning, the prices paid varied with the depth of the work, so that it was only possible to give a rough approximation. Generally speaking, he thought it might be taken that for work like the underpinning in Cannon Street £1 per cubic yard would pay for the excavation and timbering, and about £2 per yard for the concrete and brickwork. Something like £35,000 or £40,000 had been paid for underpinning in the whole course of the line; but he was certain that the results had amply repaid the expenditure. The compensation cases that might otherwise have been encountered in Cannon Street, Eastcheap, and Tower Street would have been very serious. One instance of serious damage might have amounted to the whole cost of the underpinning.

Reference had been made by Mr. Galbraith to the great depth of some of the flanges of the wrought iron beams, but he, perhaps, did not quite appreciate the fact that they were designed to carry buildings. The buildings not having been yet erected, no doubt the girders seemed rather heavy at the present time. The question to which he had alluded with regard to the long rivets had been considered, and all the long riveting had been done by hydraulic riveters, even when the work was done on the spot. No difficulty had been experienced when that method was adopted.

Mr. Galbraith, he thought, was in a little error in regard to the question of traffic. Certainly the experience both of the Metropolitan and the Metropolitan and District Company had been that the east and west traffic in London was the really valuable traffic. There was a greater demand for travelling facilities from east to west than from north to south, and it would be a most unfortunate thing for London if persons travelling between the east and the west were obliged to change carriages on the road. If Mr. Galbraith's idea were carried out, a person going from the east of London to the extreme west, for example, to Earl's Court or to stations west of it, would have to change first at Aldgate, and then at Gloucester Road or South Kensington. The experience of the two Companies since the opening of the Inner Circle line had been to accentuate what was known before to some extent—that the north and south traffic was a comparatively small item in the whole traffic of London. He could not agree with Mr. Crampton in his suggestion about getting rid of the ballast, especially in underground railways. The permanent way which he had suggested, would certainly not lend itself conveniently to the innumerable curves and changes of direction on the Metropolitan lines, and would be too rigid. Anything in the nature of a longitudinal sleeper and rail was a thing which engineers found more and more difficulty in dealing with. The difficulty of repairs on the Underground Railway was so great that they were obliged to consider what form of road lent itself most conveniently to the carrying out of repairs within the two or three hours when the traffic was stopped, between one and four o'clock in the morning. For this purpose the cross-sleeper road with a bull-headed rail was more convenient than any other method with which they were acquainted. He might mention that, during the progress of the excavation in the City, some interesting antiquities and relics of their Roman predecessors had been found, most of which were now in the Guildhall museum. One of them was a very beautiful arm of a bronze statue, which most certainly had been modelled at a time when art had attained a high standard of cultivation. Mr. Barry.

Correspondence.

Mr. T. C. Clarke submitted the following statistics relative to the New York (Manhattan) Elevated Railroad. The figures in round numbers were taken from the official reports of 1884:—Length of double track, 32 miles; cost, £9,000,000; locomotives in use, two hundred and seven; passenger carriages in use, six Mr. Clarke.

Mr. Clarke. hundred and fifty-two; daily number of trains, 2,139; yearly train mileage, 6,057,000; yearly number of passengers, ninety-seven millions; yearly receipts, £1,345,000; receipts per train-mile, 4*s.* 6*d.*; yearly expenses, £777,000; cost per train-mile, 2*s.* 6*d.*; cost per passenger carried, $1\frac{92}{100}$*d.*; ratio of passengers to seats, 75·100; net revenue, £568,000. The average time of stops on the New York Elevated Lines was twenty seconds.

Mr. Fowler. Mr. J. Fowler, Past-President Inst. C.E., regretted that illness had prevented his being present, but he had carefully read the Papers by Mr. Baker and Mr. Barry on the works of the Inner Circle Railway, and need hardly say he was personally very familiar with the underground railways of London. He would first like to say that he was grateful to his old friend and partner Mr. Baker, and he was sure every member of the Institution would be equally so, for the trouble he had taken in searching through old documents bearing upon the early history of the Metropolitan Railway, and describing so fully the works of the "Inner Circle." It was no reflection whatever on Mr. Barry's Paper to say that Mr. Baker's necessarily possessed the greater interest, seeing that it embraced the early history of the Metropolitan Railway, and that the works described were all pioneer works, and represented 86 per cent. of the "Inner Circle." Neither of the Authors appeared to have supplied the lengths of the "Inner Circle" constructed by various engineers, therefore he would do so:—

Inner Circle Railway.

		Length executed. Miles.	chains.	Percentage.
John Fowler,	engineer	11	20	86
Edward Wilson	,,	0	27	2½
Francis Brady	,,	0	28	2½
Joseph Tomlinson, jun.	,,	0	35	3½
Hawkshaw and Barry	,,	0	58	5½
Total		13	8	100

In Mr. Baker's history of the Metropolitan Railway, a proper place had been given to the late Mr. Charles Pearson, the city solicitor. Mr. Pearson, a man of great ability and influence, was most valuable in keeping the question of metropolitan railways, meat and vegetable markets before the public; but all his views were founded on a belief in the convenience and value of concentration into central stations; in this, as experience had shown, he was clearly wrong; but it must be remembered that the railway traffic to and from London was then very small compared to

the traffic of the present day. If Mr. Pearson could have foreseen the growth of railway traffic to its present dimensions, he was far too able a man to have persevered in his views of concentration. Mr. Fowler.

The only other point to be mentioned in connection with the early history of the Metropolitan Railway was one which might be interesting and encouraging to the younger members of the profession. After the contract was let and the works had been commenced on the first section of the line great public and professional interest was felt in the undertaking, but at the same time it was considered to be an experiment. At the monthly board meetings of the directors, he was often told that members of the board had been warned by engineers that the line never could be made, that even if made, it never could be worked, and even if worked that no one would travel by it. This was rather discouraging, but he had studied the work carefully, and believed in it, and the directors believed in him, and he did make it, did work it, and the public travelled by it.

The experimental character of the railway almost necessarily produced another difficulty, and that was the difficulty of raising adequate funds for the work. Necessity was truly called the mother of invention, and he was compelled to consider in every possible way how the works could be carried out with the least expenditure. This consideration led to the adoption of concrete retaining walls, and to the general use of lime concrete wherever it could be safely substituted for brickwork.

It would be observed from Mr. Baker's Paper and the diagrams that, almost every possible variety of underground constructions were met with on the early works of the Metropolitan, and Metropolitan District Railways. The Clerkenwell tunnel was through London clay, and only ordinary difficulties were encountered: but subsequently another tunnel was constructed alongside, and partially under the first, which necessitated extraordinary precautions being taken with the work. At Campden Hill the ground through which the tunnel had to be carried was chiefly gravel, and fine sand heavily charged with water, and this was found to be far more troublesome than the London clay, and occasioned special difficulties to the contractors. In any case tunnels through a town crowded with buildings must always be anxious works. Covered ways, either with a brick arch or a girder roof, might be exceedingly simple constructions when the ground was favourable and the buildings not too near, as in the case of ground cleared for a new street, or they might be works of the greatest difficulty when important buildings on each side a street had to be upheld, and

Mr. Fowler. the street traffic maintained without interruption. Many cases of this kind occurred on the Metropolitan Railway, and called forth the utmost skill and care on the part of the engineers and the contractors. Mr. Baker was quite right in saying that with covered ways, and indeed all structures in London, it was wise to use brickwork when possible, and not ironwork, and even to incur some additional expense by so doing. Oxidation with iron or steel structures was always serious enough in London; but when hidden it might be dangerous. No general rules could possibly be laid down for dealing with the numberless variety of instances of special construction required in covered ways. Each case must be separately considered, and often in conjunction with the contractor and the company's valuer. Similarly the usual rules for thickness and batter of retaining walls required, in the case of the Metropolitan and District Railways, to be often modified owing to proximity to buildings. Sometimes it was necessary to use iron struts, dispense with batter, and minimise the thickness of the walls.

Of what might be termed special works, the large sewer crossings, and the numerous gas and water mains afforded many examples, and Mr. Fowler could most cordially endorse the statement of Mr. Barry that, in all cases, Sir Joseph Bazalgette, Past-President Inst. C.E., and Mr. W. Haywood, M. Inst. C.E., gave every facility and assistance. Both Mr. Baker and Mr. Barry had fully described the process of underpinning, which consisted essentially in executing the work in short lengths and with great care under the charge of men like the late Mr. Armstrong, and the contractor Mr. Walker. The Smithfield Market was a work which had not been perhaps sufficiently described. The stations of the "Inner Circle" also were interesting examples of special construction.

It was not necessary to add to Mr. Baker's interesting history of the experiments for working the first section of the Metropolitan Railway. All the conditions were altered when it was determined to form junctions, and work in connection with existing railways of the ordinary type; because it obviously then became essential that the same engine should be capable of being worked both on the metropolitan railways and the railways with which it formed junctions. The type of engine which he had adopted after much consideration, had been very successful, and fulfilled the conditions of starting quickly and passing readily round sharp curves.

The question of ventilation had always been a troublesome one in connection with the "Inner Circle Railway." Blow-holes

similar to those adopted by Mr. Fowler many years ago on the Edgware Road were a favourite mode of ventilation with Mr. Barry, and reasonably so; but there were cases when blow-holes could not be permitted, and the required ventilation must then be obtained by mechanical means. There was no difficulty whatever in that except the cost of working. Mr. Fowler.

Mr. Robinson. Mr. JOHN ROBINSON, of Barry, Cardiff, observed that Mr. Baker had described the side walls of the Metropolitan and District railways as being of brickwork. Since these were built Portland cement concrete had come more into use. The Whitechapel extension of the East London railway, from which it branched at a point under Cotton Street, and passed under Raven Row, East Mount Street, the London Hospital, and the Whitechapel Road to its junction with the City Lines Extension, had all its side walls, including those carrying the hospital, of Portland cement concrete, also the invert throughout and the backing to the arches. For engineering works in such situations it was a most suitable material. The mode of proceeding with the construction of this extension or spur line was to timber the entire width of the covered way as in the case of the Inner Circle completion; then successively to sink trenches for the side walls, turn the arch in brickwork, excavate the "dumpling," put in the invert, and, last of all, to coat the whole of the top of the covered way with asphalt. Where the depth was insufficient for an arch, and the span not more than 25 feet, cast-iron girders of the same section as those mentioned by Mr. Baker, with brick jack-arches were substituted. Where the span was greater than 25 feet, as at the bell-mouth Raven Row, the bell-mouth in the Whitechapel Road, and across St. Mary's Station, wrought-iron girders were used. With regard to the use of cast-iron work, it seemed to be too much despised nowadays; but it was in many situations more durable than wrought iron, and less costly to keep in repair. Special care had to be taken in carrying the railway under the heavy "Grocer's wing" of the London Hospital, and the works had to be so designed as to prevent as far as reasonably possible noise or vibration from the passage of the trains. With this object the invert was deepened under the hospital, and for some distance on each side, and on it was spread a layer of tan on which the ballast was laid. The governors of the hospital appointed Mr. Edward Woods, Vice-President Inst. C.E., to advise them and to supervise the work. He recommended strong plate-girders to be placed square across the railway, with jack-arches set in cement mortar instead of a brick arch, and this was done. The walls of the hospital took their bearings skew across the girders and jack-arches

Mr. Robinson. just wherever they came. The work was successfully executed, and the means adopted to prevent noise and vibration proved satisfactory. During the progress of the work the wards above were occupied the whole time by patients—the ward immediately above the basement by children, who were never disturbed by the operations going on; but at night, when all the traffic in the streets had stopped, the women who occupied one of the upper wards were anxious to know what the knocking was that they heard. From the traffic on the railway little or no noise or vibration had been noticed by the inmates of the hospital.

At the junction with the East London Railway the old covered way had to be removed without interfering with the traffic between Liverpool Street and New Cross through the Thames Tunnel. For this purpose a shield was made of boiler-plate and angle and T-irons bent to the form of the covered way, and so as to be clear of the rolling-stock. When the iron shield was inserted, the arch was picked away above, and the bricks and mortar were prevented by the shield from falling upon the passing trains and the permanent-way below. As the removal of the arch progressed, the shield was moved forward. The exterior walls of the houses in East Mount Street and Raven Row that were underpinned stood without cracking, but the interior walls cracked slightly. Although the material found in the excavations was chiefly gravel, which was used for making concrete, clay was met with in the foundations of the side walls and invert. The sewers and gas- and water-mains under the Whitechapel Road were numerous and troublesome to deal with. The length of the spur line was 1,806 feet, and the cost of the works, including the permanent-way, wood paving in front of the hospital, and the bell-mouth and large ventilator at Raven Row, was £70,450. To this, however, must be added, diversion of sewers, £8,000; bell-mouth for the District Railway, £10,000; signals and telegraph, £1,090; water-supply, gas-service and lamps, and a few other items, making the total £91,660.

Mr. Whitley. Mr. H. Michell Whitley remarked on the great difference between the engineering construction adopted on the original Metropolitan Railway and that of the Inner Circle completion. This was more especially shown in the extensive use of Portland cement concrete in place of brickwork for the side walls of covered ways, retaining-walls, &c. The strength of this material was undeniable, though in many instances but little care seemed to be adopted to make the wall look sightly after its construction, the roughest planking being used for the mould, which left its impres-

sion on the face work after its removal. Not only was this unsightly, but the frost sooner found out the weak places. It would be desirable to pay more attention to this point, and to fill in close behind the planks with finer cement as it rose; by this means a much better appearance would be obtained; but concrete from an architectural point of view was exceedingly cold and unsatisfactory, and would be improved by being faced with brick-work, much in the same manner that some of the new sea-walls in Sussex were protected by flintwork; although it must be admitted, that the present and increasing practice of traffic managers in covering every available piece of wall, building, or bridge, with advertisements, was not an inducement to engineers to consider so fully the artistic effect of their work when executed. Mr. Whitley.

Turning now to the ventilation of the line, he would refer to the Table, showing the effect of the piston-like action of the train, in drawing in fresh and in expelling foul air; it appeared the ventilators were far more efficient than those on the Metropolitan Railway in the Euston Road which, before the erection of the present ventilating screens, were described by Mr. Tomlinson as of very little use. No doubt the large section of tunnel (originally built for the broad-gauge), would account for a great difference, and the shape of the aperture would also have an influence on the out-draught, as an aperture which would intercept the top-current and shoot it upwards would have the best effect. The in-draught, as might be expected, was in the majority of cases greater than the reverse current; but a notable exception occurred in ventilator No. 10, about midway between the Mansion House and Blackfriars. Here the out-draught was more than twelve times the in-draught, a result which needed explanation; part of this excess might be due to the peculiar shape of this ventilator exceptionally inducing an out current, and another cause perhaps was, that the arriving trains from Blackfriars to the Mansion House were often stopped by signal to allow an outgoing train to cross to its proper road; thus the suction behind the train was lost, with the result that but little, if any, down-draught took place on this road. The large number of trains, and the consequent difficulty in keeping the tunnels of the Metropolitan Railway pure, seemed to point to the line as one on which experiments should be tried with liquid fuel, instead of coal. In South Russia, the bulk of locomotives were now run with petroleum waste, from the Baku oil-fields; and if the latest experiments could be trusted, that 1 ton of petroleum was equal to from 2 to 3 tons of coal, its use (assuming it generated the same

Whitley. amount of impure vapour as coal), would reduce the impurities in the tunnel, from one-half to one-third their present amount; but as in the latest locomotives there was said to be perfect combustion, this would be probably much further reduced. The demand for this oil would probably lead to increased facilities in its transit, and in a lowering of price, whilst it was said to be perfectly safe, and such a system as deserved a fair trial on underground lines.

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24 February, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Papers on the Metropolitan and District Railways, by Mr. Baker and Mr. Barry, was continued throughout the evening.

Mr. Aspinall.

Locomotive Expenses.	London, Brighton, and South Coast. Pence per Train-Mile.			Great Southern and Western. Pence per Train-Mile.		
June half year	1882	1883	1884	1882	1883	1884
Salaries, office expenses, and general superintendence	0·088	0·097	0·093	0·254	0·222	0·214
Running expenses—Wages	2·743	2·865	2·820	2·285	2·242	2·261
Coal and coke	3·028	3·301	3·248	2·732	2·890	2·748
Water	0·129	0·128	0·193	0·216	0·201	0·196
Oil, tallow, &c.	0·516	0·552	0·513	0·294	0·327	0·334
Total running	6·416	6·846	6·774	5·527	5·660	5·539
Repairs and renewals—Wages	1·649	1·340	1·427	1·487	1·496	1·393
Materials	0·870	0·979 0·335 credit	0·848	1·387	1·599	1·671
Total repairs and renewals	2·519	1·984	2·275	2·874	3·095	3·064
Total	9·023	8·927	9·142	8·655	8·977	8·817
Gas	..	..	..	0·135	0·157	0·137
Special haulage	..	..	..	0·251	..	..
Total	9·023	8·927	9·142	9·041	9·134	8·954

Locomotive Expenses.	London, Brighton, and South Coast. Pence per Train-Mile.			Great Southern and Western. Pence per Train-Mile.		
December half year	1882	1883	1884	1882	1883	1884
Salaries, office expenses, &c.	0·086	0·090	0·088	0·218	0·211	0·195
Running expenses—Wages	2·752	2·868	2·795	2·268	2·235	2·179
Coal and coke	3·193	3·314	3·208	2·618	2·845	2·781
Water	0·172	0·124	0·159	0·249	0·205	0·246
Oil, tallow, &c.	0·528	0·622	0·450	0·387	0·344	0·309
Total running	6·645	6·928	6·612	5·522	5·629	5·515
Repairs and renewals—Wages	1·422	1·330	1·328	1·616	1·499	1·309
Materials	0·888	0·908	0·884	1·395	1·504	1·711
Total repairs and renewals	2·310	2·238	2·212	3·011	3·003	3·020
Total	9·041	9·256	8·912	8·751	8·843	8·730
Gas	..	..	..	0·128	0·150	0·132
Special haulage	..	..	..	0·244	..	..
Total	9·041	9·256	8·912	9·123	8·993	8·862

Mr. Aspinall. proving that the flanges were saved; but it must of course be added that with a bogie four wheels were used instead of two. In group No. 1 of tire sections, it would be seen that Nos. 33 and 34 exhibited very little flange wear, and these sections were only placed in their present position to show the advantage of a flexible wheel-base, Nos. 33 and 34 being from double bogie engines. In all other respects they agreed with the others with which they were grouped. With regard to the tank engines used for metropolitan traffic on the Brighton line, and which were said to have in some instances run 114,000 miles between shop repairs, these were special results, and though no doubt good, were due in a large measure to the engines being very light, namely, 24½ tons, and the wheel base being only 12 feet. On the Great Southern and Western Railway, the mileage of ten main-line passenger engines during their life had been 62,400 between shop repairs. With regard to crank axles, ten still in use had run over 430,000 miles, twenty over 350,000, and twenty others over 280,000 miles. The Author had mentioned the amount of water evaporated. He should be glad to know how he had measured it, because it was always a difficulty in dealing with locomotives to measure water accurately, and unless it was done accurately, the result was of no use. The Author had also spoken of the vacuum he had obtained in the smoke-box, and had stated that level with the middle row of tubes, halfway between the blast-pipe and smoke-box, he got from ¼ to ⅜ inch of water. In some experiments that Mr. Aspinall had recently tried, putting a gauge on the side of the smoke-box, he had got from 6 to 7 inches of water. That only showed what different conditions the smoke-box must be in when a slight variation in the position of the gauge gave such different results. As to Table II. in the Appendix, showing the performances of the Brighton Company's engines, he wished to know whether it was a statement of special or of average results. In order to test it, he had made out a very similar one, taking a period of twelve months, and he found that the average consumption per vehicle-mile with passenger engines, owing to the smaller number of vehicles hauled, was not so good as that obtained by the Author; but the average consumption per vehicle-mile with goods engines, was quite as good without any heating the feed-water at all. The average loads were practically alike. The starting load from the stations in almost every case was forty-five wagons. He had taken, as given by the Author, 3 cwt. of coal for lighting up. In his remarks, after the reading of the Paper, the Author stated that the average engine-miles run per

engine per annum were 23,700. The results obtained on the Great Southern and Western Railway in work done, in economy of fuel, and in economy of repairs compared favourably with that done on the Brighton line, as the statistics (p. 128) would show. The average engine mileage per annum was 23,236. The locomotive expenses for three years were compared in the Table, p. 129. The consumption of coal per engine-mile and per train-mile, for the same period, was as under:— Mr. Aspinall.

Half Year ending	London, Brighton, and South Coast.		Great Southern and Western.	
	Per Engine-Mile.	Per Train-Mile.	Per Engine-Mile.	Per Train-Mile.
	lbs.	lbs.	lbs.	lbs.
June, 1882	30·97	38·01	27·77	35·46
December, 1882 . . .	30·49	36·91	27·45	35·16
June, 1883	31·14	37·71	28·54	37·12
December, 1883 . . .	30·58	36·80	27·33	36·17
June, 1884	29·67	35·55	26·27	34·85
December, 1884 . . .	29·19	34·84	25·85	34·68

Mr. J. C. PARK said the Paper contained an interesting record of the Author's practice on the London, Brighton, and South Coast Railway, and it exhibited work of a highly finished character such as any railway man of large experience might look upon with admiration. It would, however, have been of still greater value if the Author had given some notion of the cost not only of the production of the engines, but of their maintenance for the last ten years. The Author had fine shops at Brighton designed by himself; but he had stated that he had not seen it necessary to purchase improved machinery or appliances. Mr. Park, on the North London line, had for several years past given considerable attention to these labour-saving appliances, and was in a position to say that he had reduced the cost of production considerably. When he joined the North London Railway Company eleven years ago, he found that his predecessor had adopted the outside-cylinder engine. He had himself been a locomotive superintendent of a railway in Canada, where the engines were all of the outside-cylinder class. There the road became exceedingly hard during the winter months, and nothing was so calculated to test axles as the hard roads of America. During the seven years he was in Canada he never had occasion to change a straight axle, although all the axles were of iron. On the North London line fifty-six driving outside-cylinder engines were now in operation, and during eleven years he had Mr. Park.

Mr. Park. never seen a straight-axle give way. The outside-cylinder engine had been adopted fifteen years ago, and he had not experienced a single failure. The North London service was very severe upon locomotives, inasmuch as the trains were constantly starting and stopping. The engine ran into the stations at full speed, and with a powerful steam-brake was brought to a stand in the length of the train. For some years past the average journeys with the outside-cylinder engines had been 47,000 miles per engine per annum. During the year an engine made sixty thousand stoppages, yet the straight axles had never shown any signs of failure; they were made of the best crucible steel, and were, he thought, very fairly proportioned. The size of the standard driving-axle was 8 inches in diameter at the wheel-seat, 7¼ inches in diameter by 8 inches at the bearings, and 7 inches in diameter in the middle; the total length of the axle was 5 feet 8½ inches. There were also thirty-seven inside-cylinder engines performing practically the same kind of service, but there had been many failures with the axles. Recently hoops had been put on, and he had every reason to believe that a crank-axle when hooped at the beginning was practically much more durable and safe. He did not think that the web of the crank could be considered as the weakest part if it was properly hooped; he thought that the crank-journal would be found to be the weakest part, and that therefore the Author had acted wisely. Much more wear might be got out of the axles if they were made stronger—if the crank-journals were made 10 inches instead of 7½. With regard to heating water by the exhaust, he thought few engineers had not either tried it directly, or had been indirectly connected with the experiment. No doubt there was a saving. He had a stationary engine, the water of which was heated by the exhaust steam, and marked economy was obtained; but from all that he had heard and seen, he believed no one was in favour of the method but the Author, who had, however, given facts and figures, and there could be no doubt that he had found it useful. Of course, as had already been pointed out, a great deal depended upon the driver. His impression had been that large leading-wheels were not always considered so reliable as wheels of a smaller diameter, but seeing that the Author had been running his engines for many years with marked success, it might be assumed that there was not so much danger in having large leading-wheels as many persons had supposed. With regard to wear and tear, there was a greater tendency for the flanges of large leading-wheels to become thin than in wheels of smaller diameter, thereby necessi-

tating more frequent turning to reproduce the requisite thickness of flange. Still there did not seem to be any danger in having large wheels, or any tendency to run off the line, seeing that the engines on the Brighton Railway ran at a very high speed, and that they had worked so long. When he was on the Great Southern and Western Railway of Ireland, the question of putting the outside crank in a line with the inside was considered by himself. The intention was to prevent knocking. No doubt the driving axle-box was not so likely to knock, but it was found that the extra weights that were put in to balance the engine caused a considerable wear in the tires, and that being considered a drawback, the plan was abandoned. Mr. Park.

Mr. F. W. WEBB had been especially struck with the remarks about hydraulic-riveting, or machine-riveting, as opposed to hand-riveting; and seeing that since 1856 the steam-riveter, and afterwards the hydraulic-riveter, had been used almost entirely at the works over which he had control, he thought he should not be doing right to leave those remarks uncontradicted so far as his personal experience went. His experience first as a boy, afterwards as a practical riveter, and then as Superintendent of the works, had shown him during a period of thirty-two years that both steam and hydraulic-riveting were perfectly reliable, and he did not remember a single case in which the plates had suffered from the action of either the one or the other. In order to give a practical proof of his statement he had brought with him photographs of a boiler made by machinery, one of the ordinary boilers of the London and North-Western Railway Company, taken out of the boiler shop, and not made for the purpose of being photographed. He had also brought a sample of the joints made by hydraulic riveting, and he had one of the rivet-heads drilled off. The joint was made under a pressure of 47 tons, and he did not think any one could say that the plate had in the slightest degree suffered from the action of the riveter. To show still further the action of the riveting, he had brought two soft copper-plates which had been riveted by a pressure of 37 tons. Here also one of the rivet-heads had been drilled off and the rivets driven out, and the meeting would see by the marks on the rivet the power that had been required to drive it out. With the soft copper there was not as much harm done as would be done by a single blow given to the hole with the drift. The day of drifting and 4½-lb. flogging-hammers, in his opinion, had gone by. With reference to the remarks of the Author respecting the making of wheels and the dishing of the washers, that had been the universal Mr. Webb.

Mr. Webb. practice at Crewe since 1857. For the last twenty years when making the wrought-iron wheels, not only had the washers been dished in the way described by the Author, but spoke had also been welded to spoke before the washers were put on, practically making the whole of the wheel a solid body. That, however, was a thing of the past. All the wrought-iron wheel fires had been dismantled, and in the place of wrought-iron, cast-steel wheels were now used, of which more than three thousand were running. Those wheels were as solid as anything could possibly be. They were cast centrifugally on a machine, placed on the top of a Brotherhood three-cylinder hydraulic capstan engine, making from 40 to 60 revolutions a minute, according to the diameter of the wheel, and he had not had the slightest trouble. Another point on which he had differed from the Author was the putting of a large wheel in front of an express engine. No one was infallible, and no one could say that at some time or other a crank-axle, a coupling-rod, or a crank-pin would not give way. His own fear of putting a driving-wheel in front was, that should a coupling-rod or a crank-pin fail, and the long end of the coupling-rod remain on the crank-pin of the front wheel, it would be apt to act as a stalking-horse, and capsize the engine and throw it off the road. He had been astonished at the small quantity of fuel allowed for the very heaviest work on the Brighton line. Considering that a large portion of the traffic on the Brighton line was passenger traffic, if the heaviest work only required 24·8 lbs. a mile, and if twelve carriages only required 16 lbs. per mile, he should be glad if the Author would say what became of the other fuel; because, on looking at some returns, the average amount of fuel burned per locomotive-mile was 29·54 lbs., and per train-mile 35·35 lbs. It should also be borne in mind that the great bulk of the coal used was the best South Wales quality. On the London and North-Western Railway South Wales coal was used to the extent of 15¾ per cent. A good deal of the coal was of the poorest quality. The Cannock Chase coal was a weak fuel, and went away rapidly. To show the difference in the quantity of coal required to do the same work, some time ago he ran for a month one link of trains on the South Staffordshire district with South Wales coal, the consumption being 25·25 lbs. per mile, and then with the ordinary local coal, when the consumption was 32·82 lbs. per mile. It was cheaper, however, to burn the poorer coal. There was less action on the tubes and fire-boxes, and the work was done cheaper with a little extra labour on the part of the fireman. Taking the goods and pas-

senger mileage of the London and North-Western in the same proportion as upon the Brighton line it would be found that the consumption was 33·75 lbs. per mile against the Brighton Company's 30·47 lbs., with their large proportion of best South Wales coal. Again, because everything should be worked if possible on a commercial basis, the percentage of locomotive expenses on the London and North-Western line amounted to 11·64 per cent. of the gross traffic receipts. That Company had to deal with a great deal of competition, while the Brighton Company had, as a rule, higher rates; their locomotive expenses, however, were 13·91 per cent. of the gross earnings. He had taken the calculation over the past five years. In the half-year before the last the amount was rather more, but he had given a fair average, and had treated both companies in the same way. Then, in getting down his expenses to 11·64 per cent., he had had to work with a practically closed capital account. Since he had charge of Crewe he had to pay for everything as he went on out of the amount he had stated. Then again all the polish shown on the specimens exhibited was not necessary for the proper working of an engine. He observed that where the engines of the Brighton Company were charged to capital account, they were charged at the rate of nearly £2,800 per engine. If he had to effect the renewals of the London and North-Western Company on the same basis he should have had to ask, on that item alone, for £113,954 more than he did ask for last year, and that amount, singularly enough, was the same amount within £461 as the difference between his percentage of working expenses and that of the Author of the Paper. That on a large line like the London and North-Western practically meant $\frac{1}{3}$ per cent. dividend. He had once been attacked by a member of the Shareholders' Audit Committee for painting the engines black. His reply was that when they paid 10 per cent. he would line them with gold. As some doubts had been expressed as to what he had been doing at Crewe with the compound engine, he might be permitted to say that he was now building nothing else for passenger work, and he had thirty such engines on the main line. During the last two years they had run 1,746,873 train-miles. He had been asked why they were not used for goods; but everything could not be done at once, and it was necessary to keep the work going, but he had not overlooked it. The compound engines he had built, owing to the absence of coupling-rods, did away with the necessity of putting the big wheel in front to get the proper weight or having balance weights behind. Engines of this class were being built for the night mail and express service Mr. Webb.

Mr. Webb. between England and Scotland. One of those engines would on Wednesday night run with the limited mail to London, arriving on Thursday morning. It would leave London again on Thursday morning, running through to Carlisle, and back again from Carlisle in the afternoon, going a round of more than 600 miles in twenty-four hours; and he would undertake to say that that would be done without ever opening the smoke-box. The consumption of fuel on such work was just over 29 lbs. per mile, including all the coal burned while the engine was standing in steam in London and getting ready for work. Some time ago he altered one of the Beyer-Peacock type of Metropolitan engine to see what could be done underground to reduce the amount of sulphur and smoke. Up to the present time that engine had run over 30,000 miles, and the consumption of fuel had been 23·9 lbs. per mile against 31·4 lbs. for the same class of engine non-compound doing the same kind of work. The Metropolitan type of engine as originally designed was, he considered, far too cumbrous and powerful for the work, and there was a great deal of coal expended in the friction with the coupling-rods and tires in going round sharp curves. Many members had no doubt seen the standard double-ended engine he had been building for some time, of which one hundred and twenty were at work. He was now compounding that class, and hoped to get even better results than had been obtained on the Metropolitan District Railway. He was now preparing the necessary patterns for a compound goods tank-engine for main line work, and he felt sure that with that class of engine an even greater percentage of economy would be effected than with the passenger engines, for the reasons stated by the Author of the Paper. The tank engine was the same in general design as one hundred and fifty engines now working on the line. The centre of gravity was so arranged that there would be a maximum of 15 tons on the leading pair of driving-wheels, which were coupled to the low-pressure cylinder, and a maximum of 24 tons and a minimum of 18 tons on the two pairs of coupling-wheels behind. The engines would carry 1,300 gallons of water, and be fitted with a pick-up. He intended to use them on the main line for goods work. He thought that the day for tender engines, except for express work, was gone.

Mr. Cowper. Mr. E. A. Cowper said that it appeared that the Author had given due consideration to the ensuring the safety of the engine, even if the crank-axle broke, and as it was now a well ascertained fact, that all crank-axles broke if they were kept in use too long, it was a most important point to be attended to. The large flat

surfaces of the backs of the wheels, and the faces of the axle-boxes, went far to assist in keeping the engine on the road, if an axle broke. In reference to the torsion on an axle ruining it, he knew of several cases where torsion in one direction, and then in the other, continued for a length of time, completely tore the shaft to pieces; this was the case with a bell-crank shaft in a locomotive-engine called the "Experiment," made by Richard Roberts, in the early days of the Liverpool and Manchester Railway. With regard to the rims of the wheels being made very stiff, he had no doubt it was very good for the tires, whatever it might be for the road. Mr. Cowper.

Mr. JOHN ROBINSON, of Manchester, said he agreed with Mr. Webb's remarks with reference to steam or hydraulic-riveting, as compared with hand-riveting. When the first steam-riveting machine was brought out by Fairbairn, there was a fixed distance from die to die at the end of the stroke; therefore, whether the rivet was long or short, the blow which drove up the rivet-head was arrested at a fixed point, and the consequence might be, as the Author had stated, that if the rivet were too long the machine would still go up to the point at which it was arranged to travel, and the plates might be burst. But, on the other hand, he thought that any one acquainted with locomotive practice for the last twenty or twenty-five years, must have observed the gradual tendency on the part of locomotive makers and of gentlemen who specified boilers to be made in a certain way, to have them riveted by hydraulic-pressure, because whether the rivet was long or short, the same amount of pressure came upon the rivet and filled the hole. One point that had struck him as very remarkable, was the growing use of steel plates for boilers. One of the great difficulties that every one foresaw at first in connection with the use of steel plates, was the question of tensile strain, the danger of fracture from unforeseen constituents entering into the manufacture of steel. What had been the fact? He thought, looking at the whole practice of locomotive makers and designers in the country, it would be admitted that the tendency was, first, to use steel for boilers, and secondly to use drilled holes for the rivets by which boilers were to be put together. No one, however, had suggested that these things should be done by hand, because hand-riveting often led to drifting, and drifting often led to the breaking or distortion of the plate. Bad work was concealed by careless men in the hand-riveting process, which was not possible in the hydraulic process. He was, therefore, certainly inclined to follow the practice of Mr. Robinson.

Mr. Robinson. Mr. Webb. Mr. Robinson's experience, and all that he had heard of the experience of others, led him to the conclusion that it was best in the case of steel plates to employ drilled holes and hydraulic pressure both for tightness and durability. He was glad to find from the Paper that the piston-rings of Wakefield were still in good favour on the Brighton Railway. He was also glad, as a designer of the various parts of engines, to find that the eccentric sheaves were made of cast iron, and that notwithstanding the reciprocating motion of the clips or straps they were also made of cast iron; and that although the two parts rubbed together and were of cast iron, the Author had found that there was no appreciable wear for a considerable number of years. Bearing in mind the resistance of the valve to the motion of the eccentric, he would ask why, when the motion was like that of a piston in a cylinder where there was no such reciprocation, the Author made the piston-body of brass? If the Author were to give him an order for an engine, he should certainly ask to be allowed to make that of cast iron as well as the eccentric sheaves, because he thought it was less dangerous to make the piston-body of cast iron, with cast-iron packing-rings, than it was to make an eccentric of cast iron with cast-iron straps. With reference to the work produced from the machines themselves, those who had made locomotive-engines for many years would know that the work produced was better, because the surfaces were not frittered away by draw-filing and other processes of that kind. He might remind the Author that he was the master in the shops in Brighton, while Mr. Robinson was only the servant in the shops in Manchester. He had to put on polish in order to make the things look well, and to take off a number of sharp edges which the Author said were of no consequence. He entirely coincided with the Author's views in this respect, but there was a difference between a maker who was not the master, and a locomotive-superintendent who was the master in his own shop.

Mr. McDonnell. Mr. A. McDonnell had no hesitation in saying that hydraulic-riveting was superior to hand-riveting. He did not mean that hand-riveting could not be made exceedingly good, but he referred to average work, and any one who had looked over a large amount of riveting must have seen much bad work done by hand. The plates were damaged by drifting. The great point in connection with drifting was that it was a proof of bad workmanship. Then the riveting itself was bad. The rivet was driven through two holes that were foul, and it ended in a vast amount of inferior work. He had seen an enormous amount of extremely bad work done

in that way. For one riveter that would make a good locomotive-boiler, there were hundreds like those at work in ship-yards, from whom to pick hand-riveters. The Author stated that he heated the plates of the boiler-rings before he bent them. Mr. McDonnell had not been in the habit of doing that, and he thought that if the practice were adopted with steel plates a good deal of damage might be done. If the steel plate was heated and passed through cold rolls and stopped for a short time in passing through them, the steel plate would get chilled along the line where it touched the rolls, and it would be likely to show bad results. With reference to the design of the boiler, the Author had stated that he placed the dome on the ring of the boiler next the fire-box. He did not think it was a very serious matter, but that was not the ring that he himself should select. He thought the ring of the boiler next the fire-box was the weakest ring in the whole boiler, and it would be weakened still more by the hole cut for the dome. The end of the boiler barrel that joined the fire-box was not nearly so stiff or so good as the end that joined the front tube-plate; it was more likely to get out of shape and it was certainly not the ring that he should select. With regard to crank-axles, he thought it was possible to put more metal into a crank-axle, without making it any stronger. He saw no reason why the central part of the crank-axle should be made so very strong. A crank-axle never broke in the middle except from some flaw. What broke it was the constant opening and closing of the throw, and the more the spring of the axle could be distributed, the less chance there was of its breaking. It always broke in some place where one part of the axle was stiffer than another. That was generally where the centre of the axle joined one of the cheeks, or where the pin of the big end joined the cheek. The axle was there considerably stiffer than at other places. A uniform degree of stiffness or of elasticity was, he thought, the thing to aim at. He did not believe the life of a crank-axle would be saved by making the web broader and thinner, even although the sectional area was increased, because there would still be the part that had a great deal of spring connected with a pin which had little or no spring. With reference to the placing of the outside coupling-rod on the same side as the throw of the crank, he had many years ago tried some experiments on that point, as mentioned by Mr. Park, putting the outside pin on the same side as the crank; but he found no advantage in the practice. A slight strain might be thrown on the crank which was not necessary, and there was the evident disadvantage

Mr. McDonnell.

Mr. McDonnell. that the outside pin and the outside coupling rod had to be counterbalanced instead of being used as part of the counterbalancing. The Author had referred to the counterbalancing as having been shown by Mr. Crampton in 1850. Mr. McDonnell believed that it was in 1845 that the counterbalancing of the engine was first spoken of by Fernihough, and afterwards, he believed, by Mr. Heaton. A Paper was also read on the subject before the Institution of Mechanical Engineers, on the 13th of June, 1848, by Mr. J. E. McConnell. Mr. Haswell, of Vienna, patented a system in 1847, and Mr. Nolland, of Stuttgart, first explained the theory in 1848. But the real knowledge they had upon the matter was due to Mr. Le Chatelier, who published it in 1849. All information as to the counterbalancing of engines was based upon the calculations of Mr. Le Chatelier. He observed that the Author used the girder beam for the stay for his fire-box top. He thought that for large boilers the beam was certainly better than the stay similar to the side stays to the fire-box. He had seen a good deal of distortion, parts of the roof of the fire-box forced down, and the tube-plate greatly distorted by the use of the other stays in large-sized boilers. As to the rims of the wheels, he agreed that it was necessary to keep them stiff. He had traced a number of broken tires to the fact of the rim of the wheel being broken. It was not an uncommon practice to allow the rims of wheels to remain unrepaired, or at least, to have them repaired so badly, that after running a short time they broke again. If the rim of the wheel was very thin, although the tire might stand at first when it was thick, when it was turned down a little there was a thin tire upon a thin rim, and if the rim was broken it made the matter worse, and the tire would be likely to break. He also noticed that the Author used the hind damper. Mr. McDonnell had been in the habit of using two dampers, one in front and one behind, and he had often observed the different ways in which different engine drivers made use of them. He did not think that the Author followed the best practice in making the fire-bars of wrought iron. Cast iron was better and cheaper. Fire-bars were more expensive items in an engine than most persons supposed, and they required a good deal of attention. A good thing to protect fire-bars was limestone; it kept the clinker off, and it was superior to fire-brick. As to the question of compounding engines, he had not given it as much consideration as he should have liked to do; but he was inclined to be in favour of it. He had seen a great deal of Mr. Webb's work, and it appeared to him

to be perfectly sound and good. He agreed with Mr. Webb in not liking a large leading wheel, and coupling the front wheel in engines for fast work. If the front wheel was coupled, and the hind wheel a light one, in the case of a bad road, of which he had had a great deal of experience, the engine would be very much heavier in front, and a great many more leading springs would be broken in such an engine than in one that was properly balanced. The best position for the centre of gravity of an engine, not taking into consideration its wheels, was a little in front of the driving axle. Mr. McDonnell.

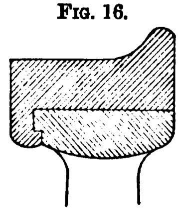
Mr. W. Adams (of the London and South-Western Railway) said that the Author claimed, in favour of his arrangement of the driving wheels in the Gladstone engine, that he had placed them at the front or heavy end of the engine, so that no artificial weight was required at the trailing end. But in designing an express engine Mr. Adams thought that the question of the weight of the engine should be secondary to that of making the engine as perfect as possible, and adapting it to run at high speeds with safety. He had found by experience that the steadiest-running engines at high speeds were those which had a bogie in front. True, with that arrangement it was necessary to put 2 or 3 tons of weight in the cast-iron foot plate behind the fire-box; but that weight was put where it was doing useful work, and the arrangement, he thought, was better than the other. At any rate, he felt safer on an engine of that kind. The Author claimed for his method that the coupled wheels being at the front or heavy end, and there being light wheels behind, the engine would run more steadily, and the trailing wheels would adapt themselves more readily to the curves, the trailing end being flexible. That was so far true. An arrow was weighted at the point to make it shoot straight, and that was proper as far as the arrow was concerned; but a locomotive had to adapt itself to curves—sometimes sharp curves round which it had to run at considerable speed. The question therefore was, was it not better to make an engine elastic at the front end? He thought that it was so. Nothing in the construction of an engine would give more confidence to a person travelling on it than a compensating arrangement in the front enabling it to suit all conditions of the road, the wheels radiating to the curves, and distributing the weight in a proper manner on the other wheels, the bogie taking the weight on its centre, and dividing it equally among its four wheels, leaving the remainder for the driving weight. The arrangement of carrying wheels next in value to the bogie was in Mr. Adams.

Mr. Adams. his opinion the radial wheels, which Mr. Webb had adopted on his compound engine. They were guided laterally by springs; and although in a full-sized engine of great power there was very little space for lateral play, he cleverly arranged the frames so as to gain the thickness of the frames for the required clearance. With reference to the heating of the feed-water, he had found most of the engines on the South-Western Railway fitted with the heating apparatus; but when he took charge of that line, the system was going out of use, it having been found to give a good deal of trouble, without any corresponding advantage. He had substituted injectors for the heating apparatus, donkey-pumps, &c., and had found a great advantage in lessening repairs, without any increase in the consumption of fuel. From the pains which the Author took in all matters of detail, he felt quite sure that he had achieved the advantage which he claimed in regard to fuel. That, however, had not been Mr. Adams' experience with the South-Western Railway heating apparatus. It was found to be a complication, and, as the most important thing about locomotives was simplicity, he had done away with it.

Mr. Reynolds. Mr. Edward Reynolds said that he would confine his remarks to a rather important matter of detail, namely, the tires. He was rather surprised to hear that for a certain size of tire an allowance was made for shrinkage of the thickness of a sheet No. 19 Birmingham wire-gauge, and for another size another arbitrary gauge. When he first became connected with the steel trade, there was occasional trouble, now unknown, from the breakage of new tires, both of iron and of steel, from being too tightly shrunk upon the wheels; and one of the early things he was called upon to do, was to fix upon a proper allowance for shrinkage. There were at that time only two other makers of steel tires, Krupp and the Bochum Company. The former had recommended an allowance for shrinkage of $\frac{1}{110}$-inch per foot of diameter, and the latter $\frac{1}{72}$-inch per foot. He fixed upon one thousandth part of the diameter as being a proportion which every manager and foreman could easily remember, and as being justified by the average of safe practice; and as it was for several years printed upon the invoices of his company, he supposed that it had been generally accepted as a standard. Of this allowance for shrinkage at least one half, but varying with the proportions of the wheels, would be found to be taken up in compressing the body of the wheel, and the remainder in extension of the tire, so that the resulting strain upon the latter, estimated by its elongation, would not exceed about 5 tons per square inch of section.

His motive for bringing up this subject was to direct attention to the desirability of pressing the wheels into the tires cold, as the axles were pressed into the wheels. So long as the tires had to be expanded to allow the wheels to drop into them, it was impossible that the retaining hooks which were now almost universally used could tightly fit their places; they must be slack by at least as much as the tire had been expanded larger than the body of the wheel, whereas, of course, if pressed together cold the fit could easily be made perfect. Having put large numbers of tires on in this way (Fig. 16), he might state that when the above-mentioned allowance of one thousandth part of the diameter was made in boring the tires, a pressure of 20 tons per foot of diameter of the wheel would be found sufficient to put them on, say, 70 tons for a wheel $3\frac{1}{2}$ feet in diameter, 120 tons for a 6-foot wheel, &c., assuming the wheels and tires to be of average proportions, so that a press, capable of giving 200 tons pressure, would serve for the largest wheels in use. With a properly arranged press, the operation was far more simple, easy, and quickly performed than pressing the axle into the wheel, which required considerable care to do perfectly, and it appeared remarkable that the practice was not general. Mr. Reynolds.

FIG. 16.



Mr. D. JOY asked for some further information with reference to the diameter and form of the blast-pipe; its height above the level of the tubes, and the result gained therefrom. Those points he had found, in his old locomotive experience, to have a very material influence on the saving of fuel. Mr. Joy.

Mr. DRUITT HALPIN observed that the Author had given in Tables VII. and VIII. the degree of vacuum in various parts of the fire-box and smoke-box. It would, he thought, be interesting to know with what kind of instrument the measurements were made, because an instrument that would measure to $\frac{1}{8}$ inch, when the engine was running at 50 miles an hour, would be of very great value. Of the figures relating to evaporation, 12·6 lbs., 11·6 lbs., 13·1 lbs., and 12·25 lbs. of water per lb. of coal, the lowest was 11·6 lbs. He found that the mean temperature of the smoke-box was 362° Fahrenheit, and assuming the temperature of the air to be 62°, this gave a rise of temperature of 300°. Taking 24 lbs. of air as necessary for the combustion of 1 lb. of coal, and the specific heat of air as 0·237, then $24 \times 300 \times 0{\cdot}237 = 1{,}706$ heat-units were escaping with the smoke; and, if the total calorific power of Aberdare coal was 14,858 units, this left $14{,}858 - 1{,}706 = 13{,}152$ Mr. Halpin.

Mr. Halpin. units available for evaporation. The mean temperature of the feed water was 142° Fahrenheit, and the steam pressure 140 lbs. per square inch. The total heat of steam of this pressure being 1,224° Fahrenheit, 1,224 − 142 = 1,082° had to be added per lb. of water evaporated, and 13,152 ÷ 1,082 = 12·15 lbs., which showed that the stated evaporation was equal to 95 per cent. of duty theoretically possible. Taking the highest evaporation at 13·1 lbs. of water per lb. of coal, this gave an efficiency of 107·6 per cent. These percentages of efficiency were of course exclusive of the 20 per cent. stated by the Author as the additional water returned to the tender by part of the exhaust steam being condensed, which was led back from the cylinders. By including this quantity the efficiencies were raised to 114 per cent. and 129 per cent. The Author had also given in Table VI. the detailed boiler-pressures at the different times when the indicator-diagrams were taken, and they were very valuable; but in one experiment, when the speed of the engine was 20 miles an hour, the boiler-pressure was 140 lbs., and the steam-chest pressure 135 lbs.; while in another experiment when the engine was running 55 miles an hour, the boiler-pressure was 135 lbs. and the steam-chest pressure was the same. Referring to the question of compound engines, the Author stated that he should like a compound goods engine but not a compound passenger engine, because the cut-off was so early. By the diagrams he showed that the large passenger engine was doing a mean duty of 529 HP., and surely when the performance of an engine obtained so high a figure it was time to compound. All marine or stationary engines of that kind were compounded. The lower Table given by the Author was exceedingly interesting. The maximum HP. was stated to be 667, and the mean HP. 529. The maximum traction on leaving the stations was 11,590 lbs., the mean traction was 4,477, and the mean speed was 44·3 miles an hour. Multiplying that mean speed by the mean traction of 4,477 lbs., the mean HP. on the draw-bar would be found to amount to 528, or 99 per cent. of the total HP. He understood that the draw-bar shown was the actual one used. He hardly thought it possible to get correct results with such an instrument. The Locomotive Superintendent of the Eastern Railway of France had made an elaborate series of experiments of that kind with a very delicate and complete apparatus, and the result was that of the total indicated HP. given out by the engine only 42·5 per cent. in one case and in another 41·6 per cent. were delivered at the draw-bar. In the same experiment, in one case 34·2 per cent. and in another 35·6 per cent. of the total power indicated was absorbed by the bare friction of the

engine mechanism, apart from the engine and tender considered as vehicles. Seeing that the traction was so small a percentage of the total power, those figures perhaps would be capable of some further explanation. Mr. Halpin.

Mr. J. WOLFE BARRY observed that, although he had not any great experience in the riveting of boilers, he should like to bear testimony to the value of hydraulic-riveting for girder work, both in very thick and in thin plates. In all cases he greatly preferred hydraulic-riveting to hand-riveting. He had not experienced any of the drawbacks to which allusion had been made in splitting or damaging plates. He had on several occasions noticed that very little burning fuel was emitted from the funnels of the locomotives of the Brighton railway. The Author had placed on the table a sample of ashes from the smoke-box, and he would observe that they were creditably small. He did not mean to say that there were never seen on the Brighton railway any of the large burning coals like sky-rockets noticeable on some railways, which were so dangerous to adjoining crops and other property, but there were from the Author's engines very few compared with many other locomotives. He considered it a disgrace to a locomotive superintendent when a stream of incandescent coal issued from the funnel, considering that the Author had been able to reduce it so very considerably by properly proportioning the blast-pipe, fire-box, and tubes, to the work that had to be done. He should like to have a little more information as to the amount of vacuum found in the smoke-box and fire-box when the engine was working with its heaviest loads, because the practice of one locomotive superintendent in that respect was very different to the practice of others. He should also like to get some further information as to the system of electric lighting adopted on the Brighton line, which he understood was being worked either from the locomotives or from the carriage-wheels. Some improvement in the lighting of railway carriages was urgently needed, and he looked forward with confidence to the future of the electric light for this purpose. Mr. Barry.

Mr. C. D. FOX said he thought the Author's experience of hand-riveting must have resulted from his having the complete control of the Brighton company's works, and from his careful selection of the men employed to carry it out. To those who, like himself, had to deal with locomotive work from different parts of the kingdom, the comfort obtained from the introduction of good hydraulic- or steam-riveting was extreme. Engineers could now get correct work, such as formerly they had great difficulty Mr. Fox.

Mr. Fox. in obtaining in some parts of the country. There was another point on which he should like information, although it was not of a mechanical nature. It was a matter in which interest was being taken in connection with some of the Indian railways. It was well known that in America, and he believed in parts of this country, engines were quite dissevered from any personal connection with the men driving them. Those who had seen the Brighton Company's engines must have admired the beautiful appearance they presented, and must also have seen inside the cab of the engine the name of the driver. The Author appeared to be a strong believer in attaching a personal interest to locomotives. The question was an important one, and he should be glad to know something of the Author's experience in connection with it, as to the effect upon the men and upon the economical working of the engine.

Mr. Stroudley. Mr. STROUDLEY, in reply, thanked the members for the consideration they had given to his Paper, and for their friendly criticisms. The object of the Paper was not, he said, the question of a proper locomotive for everybody; it was to give a record of the details which he had worked out for the particular railway on which he was employed, leaving persons with other views to carry them out in their own way. Those who had taken a new departure, deserved thanks for their trouble and for the ability and energy they had exhibited. It was well, perhaps, that a Paper should be brought forward giving the exact details of the duty performed by one kind of the old form of locomotive as a datum with which to compare the improved forms. With reference to the method of counter-balancing, it had been urged that the additional weight in the driving-wheel would tend to make it wear the tire in an irregular manner. If it was considered that the weight moved from one side of the axle to the other was a revolving weight, it would be seen that it only required an additional amount of revolving weight to balance it. His reason for adopting the system described was his experience of the extra durability appertaining to the outside-cylinder engine. He had found that the axle-boxes, side-rods, and other details would endure much longer than those of the inside-cylinder engine. This, he believed, was due to the uniformity of motion in one direction. With reference to the date at which the proportioning of the balance-weight was introduced, he himself saw it in a steamboat some years before 1850. He also saw the model made by Mr. Crampton exhibited in Birmingham in 1850, which demonstrated the whole question. As to the question of riveting by steam- or hydraulic-power, having cut to pieces

a number of locomotive boilers made by the best firms, and having found plates cracked from hole to hole, he came to the conclusion from the burr made by the rivets between the plates, that the plates had been burst by the extraordinary pressure brought to bear upon the rivets. It was twenty years since he started making boilers by planing the edges, heating the plates, bending them, and afterwards drilling them, and he had never changed that method. Speaking as an officer of the Brighton Railway, he might say that he had, perhaps, forty or fifty more boilers to make, and then he should have completed all that would be required, so that it was not worth while to put up a plant of special character to rivet boilers by machinery, as Mr. Webb could afford to do, representing, as he did, a large and wealthy company. Power-riveting was a very delicate operation, and unless it was very carefully managed it would put into the hands of the men the possibility of doing very bad work, which could not be found out until some casualty had happened. The drift was never used in the Brighton Railway shop; but he maintained that the drift was no more mischievous than some of the later tools. The hydraulic machine was now enabled to give a certain pressure which could be predetermined, and the specimens exhibited by Mr. Webb were proofs that it could be used without spoiling the plates. He had many years ago adopted the plan, in putting on the wheels, of making them so much smaller than the axle that it required a pressure of 12 tons per inch of the diameter of the axle to force them into position. When that was done, the wheel would stay there, not requiring keying or fastening in any other way. He believed the practice was common in America. He had never had occasion to take a wheel off in consequence of its being loose, except in one instance when it was found that it had been put on loose. He had applied the same principle in putting on carriage-tires, and he had never had a broken tire from a wagon, carriage, or engine, on a wheel of his own design. Having been so fortunate, it had not occurred to him to go to the expense of a special machine for putting on tires. These were put on after being heated with a slight wood fire to 700° or 800°. With regard to the wheels the heavy rim was made to support the tire between the spokes as a girder when the tire itself was worn down to a degree of thickness insufficient to carry the load. When this was done with a rim of that description, the tire would become elongated under traffic as soon as it became too thin to carry the load upon the wheels. Table V. showed the advantages of the use of hot water. In order to measure the quantity, he had a tender filled Mr. Stroudley.

Mr. Stroudley. with water; the contents were run out into a 10-gallon vessel, accurately measured, a float was fitted to a staff, and it sank into the water. For every 10 gallons of water taken out a mark was made, and the staff was afterwards used as a measure before the engine started, and again at the end of the journey, and the amount taken out was assumed to have been evaporated. Careful tests had shown that about 20 per cent. of the steam exhausted passed back into the water by the heating apparatus. With reference to the coal used to raise the steam, a careful measurement was taken. The tender was swept out, and a certain quantity of coal was put on; at the end of the journey the remaining coal was removed and weighed. In that way it was almost impossible to err very much, especially when the trials were repeated. He had carried out a great many trials before bringing the results to the Institution of Civil Engineers, and they had all corroborated his statements. To measure the vacuum he had used an ordinary bent tube water-gauge, such as was used for measuring gas-pressures. He applied it to the side of the smoke-box; and a pipe was led inside. The maximum vacuum in the smoke-box in an express engine, with 330 tons of train, running at train speeds, was 3½ inches of water. By passing a tube from the water-gauge through one of the flues in the boiler in the space above the brick arch in the fire-box, and putting a protector at the end, he had found that the maximum vacuum was nearly 1 inch less than in the smoke-box, showing that it took 1 inch of water-pressure to force the gases from the fire-box to the smoke-box. By passing the tube up the funnel, 12 or 14 inches of vacuum could be obtained. He had tried the vacuum in the ashpan, and he had found it to be from ⅛ to ½ inch. By shutting the dampers, and closing the fire-door, the vacuum in the smoke-box would attain 12 or 14 inches. In justice to his predecessor, Mr. John Craven, he ought to state that the heating appliances were in use on the Brighton Railway when he joined it. The late Mr. J. H. Beattie, M. Inst. C.E., had also effected an arrangement for heating water, but after it had passed through the pumps. At any rate, his system was by conduction; he did not bring the steam into direct contact with the water. It had been urged that turning the steam back into the water would hurt the boilers. He had taken tubes out of fire-boxes in boilers that had been running eleven or twelve years on the Brighton Railway, and he could not find a rust mark, or a single sign of corrosion or deterioration in any part of the boiler, with the exception of the front tube-plate. As to the position of slide-valves below the cylinder there was a clear exhaust; that was sufficient;

Mr. Stroudley.

it also gave cheeks of the crank of 5 inches. The cheeks of the crank were the weakest part. The cranks broke usually through the cheek, and generally through the inside one. After careful tests, he was satisfied that the breaking of the crank was caused by the pressure of steam. He had found that the crank-axle was deflected twice as much as a straight axle of the same size; and the steam threw a strain upon the crank-axle three times as great as that due to the vertical weight upon the axle-boxes which it had to carry. As to the side-rods, he had adopted the method described for the last fifteen years without a single side-rod breaking. The different parts of the locomotive shown were not made for the purpose of exhibition; but would be put into work in due course. They were the best pieces that could be selected, but beyond that they differed in no respect from the ordinary practice. They were finished by machine tools of the ordinary kind, no files or hand work being spent upon any part. The tender engines cost at the rate of 5·57*d.* per lb., or £51 per ton. The tank-engines cost 6·63*d.* per lb. It should be remembered that many of the original engines were getting old, and required an undue proportion of repairs; but during the past year the expense for renewals and repairs was only 2·24*d.* per train-mile, and 1·89*d.* per engine-mile, no train-miles being allowed for shunting. The passenger engines stopped eighteen thousand eight hundred times a day, or ninety-three stoppages per engine per day.

In reply to Mr. Webb, the quantities of coal shown in Table II. were the quantities consumed under the circumstances set forth in the Table; and were exclusive of lighting up. The weight of train drawn, however, varied, and the consumption of coal with the goods engine was very high in proportion to the miles run, in consequence of delays and heavy shunting: the average speed of the goods trains was only about 3½ miles per hour, from the time the driver commenced until he finished work: and there were only a very few through goods train on the railway. In addition, some of the old types of engines were still working, which burned 6 lbs. of coal per mile more than the engines represented in Table II. As the cost of the coal was made up of 59 per cent. for carriage, it would evidently not be economical to use a low quality of fuel. The locomotive expenses could not be judged by the traffic receipts, the real test being the cost per train- or engine-mile; either of which would give the same result, if the same method of computing miles were adopted on all railways. The remarks of Mr. Webb, as to the cost of the engines charged to capital, referred

Mr. Stroudley. to exceptional cases; the average charge to capital for the four hundred and ten locomotives on the Brighton Railway stood at £2,370 each. With respect to painting engines, the cost could not vary much since the labour was the same, no matter what the colour might be; and the colour used on the Brighton engines cost only about 16*s.* per cwt. The total cost for decorations, such as lining out, &c., only amounted to 15*s.* per engine, so that whether this were done on the Brighton system or on the London and North-Western system, it could not seriously affect the dividend. The London and North-Western Company effected a great saving on the cost of tenders, by having adopted years ago the arrangement introduced by Mr. Ramsbottom for picking up water from troughs laid between the rails. Other railways, however, not being so situated had to provide tenders of more costly character, and this tended to swell the cost of each engine.

The best answer he could give to Mr. Cowper's remark, as to the elongation of the tire, was that if the wheel-rim was of proper strength, the tire did not break, but when it became too thin for the weight it had to carry, it elongated and slackened when a new one was substituted.

Steel plates were used for the Company's channel steamers, both for the hulls and for the boilers; but there had been no change from the best Yorkshire iron for locomotive boilers, seeing that nearly the whole of the engines required for this railway were completed. The Author had adopted exactly the same mode of manufacture in the steel marine boilers as in the iron locomotive boilers, with the exception that the plates were bent without being heated.

The gun-metal piston had been used for the express-engines, it being considered more trustworthy than cast iron at high speeds. The actual difference in the cost was not great, for the metal could be re-cast for a small sum. Cast-iron pistons and slide-valves were used in the goods and other engines working slower trains. He had employed cast-iron slide-bars for the last twenty years, and none other. He submitted specimens of work entirely finished by the tool, and without hand labour or polish, other than that left by the cutting-tools; with the object of allowing the students and younger members of the Institution an opportunity of seeing what could be produced by the ordinary drilling, planing, slotting and shaping machines, and lathe. The dome was placed in the position shown, as the largest amount of steam was generated about that point. It admitted easy access to the boiler, and did not obstruct the view of the driver, as it would if placed further

forward. The manhole-ring, now generally adopted, was introduced by him in 1862; and it restored to the boiler more strength than was lost through the manhole. This form of mouth-piece had been approved by the Manchester Steam Users' Association, and adopted generally by locomotive-makers. He had fitted all the engines, at one time, with a damper at each end of the ashpan. He found that the drivers would not open the front one if they could avoid it, as the blast forced holes in the fire, and lifted pieces of live coal up into the tubes, from whence they were carried out at the top of the funnel, causing fires, &c. When the back damper was used, the supply of air was more evenly diffused over the area of the grate, and less coal was burnt. Cast-iron bars were formerly employed, but with South Wales coal they gave great trouble by melting. Wrought-iron bars cost no more per ton, and the scrap was saleable, which was not the case with burnt cast-iron. Chalk was put upon the bars by all careful drivers to protect them from the intense heat of incandescent Welsh coal; and this protection was further assisted by the water in the ashpan. He agreed with Mr. Adams that for a crooked or badly constructed road, the bogie offered many advantages; and for this reason, over the cheap new lines in America, it was found to answer so well that it was still retained, although there the main roads were now equal to, if not better than those in England. American engineers had, however, tried many expedients to obtain more heating surface, and with large driving wheels behind this was difficult, whereas in the "Gladstone" type of engine, 1,500 square feet of efficient surface could be easily provided. However valuable a feature the bogie might be at the front of an engine, it was not so good an arrangement when at the rear, as in the case of a tank-engine having a bogie at one end. When the bogie was at the rear, it tended to control the movement of the engine; the short lever between the flanges of the leading and driving wheels having to overcome the force of the lateral springs placed in the bogie; and this, in his opinion, constituted a source of danger when an engine was running with the bogie in the rear. One of the leading principles in the design of his engines was to have them all alike; and he therefore adhered to the simple six wheels and short wheel base. He used hydraulic pressure for putting on tires of carriage wheels; but his system differed somewhat from the old practice of boring the inside of the tire conical, and forcing the wood wheel in, as by this process the wood was not equally compressed, and its full value was not obtained. Many years ago he designed a gathering-in ring, which was a conical hoop, as large as the wood centre at one end, and as

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Mr. Stroudley. small as the tire at the other. The wood wheel was pushed through this ring into the cylindrical tire, giving about $\frac{1}{4}$ inch compression; this could not be obtained with a taper tire. Engine tires were put on by slightly heating them, and allowing them to cool upon the rim. The wheels were to standard sizes from 4 feet to 6 feet 6 inches, each size increasing by 6 inches. The shrinkage allowances objected to by Mr. Reynolds were not by rule of thumb, but were exact quantities suitable to these diameters.

The suggestion had been made that a large portion of heat passed up through the funnel; this, however, would depend upon the velocity, as well as the temperature of the escaping gases. The steam-pipes and proportions of these engines were such as to permit the full boiler-pressure to be maintained in the steam-chest; but the driver sometimes partially closed the regulator for the purpose of meeting the conditions of the rails, &c., at various points on the road, and this accounted for the difference. With reference to the Table, which gave the HP. at about every mile, the actual indicator cards being also exhibited, as well as the gradient and rate of speed; it had been suggested that a curved line showing the HP. and speed should be laid over the section of the line, and also that one of the tractive power given off by the engine, would be an advantage: he therefore had a spring, 20 inches long, specially constructed by Mr. Timmis, to measure the tractive power. This was fitted to the drawbar in the tender, and its compression gauged by a scale, which had been made by testing the spring in the shops up to 7 tons. By reading this scale at various parts of the road, the effort given off by the engine to the train was obtained. These particulars were not ascertained on the same day as the former, although the journey was over the same ground. The weight of the train, as noted on the Table, was less, there being only twenty-one carriages instead of twenty-three; but a very strong side wind blowing, so that the amount of power given off by the locomotive was greater, although the load was lighter: and this accounted for the apparent discrepancy. A careful test had been made by running an engine of the "Gladstone" type, empty, that was, without any train, from London to Brighton, to ascertain the amount of fuel that the engine would consume; and although the time on the journey was prolonged to two and a half hours in consequence of signals, the total amount of coal burnt was only 7 lbs. per mile. He was of opinion that it did not take more than this quantity to work a locomotive when taking a train, and thought there must be some error in the statement as to the very small amount of useful tractive power obtained by the

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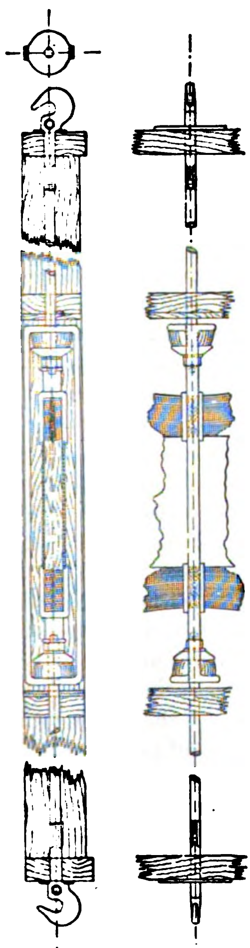
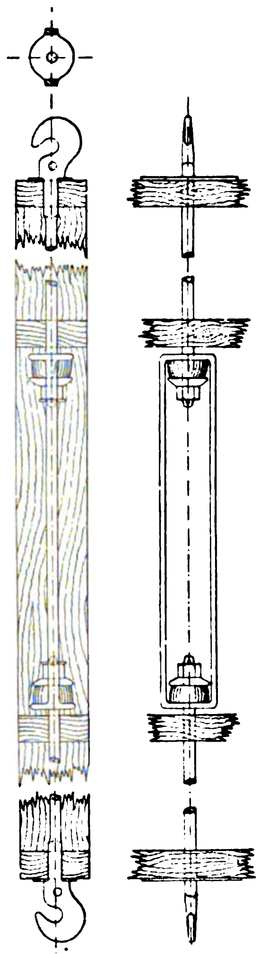
Eastern Railway of France. As the indicator diagrams were taken when the engine was working under ordinary circumstances to ascertain the amount of power required to haul a train at time-table speed, the maximum HP. was as shown, namely 675; but had the train been heavier, or a gale of wind blowing, the HP. would



FIGS. 17.

CARRIAGE DRAW-BAR.



FIGS. 18.

WAGON DRAW-BAR.

Scale $\frac{1}{8}$-inch = 1 foot.

probably have risen as high as from 1,000 to 1,100; and diagrams had been obtained from the "Gladstone" engine proving that it was capable of exerting that amount of force. This would account, therefore, for the difference in the HP. at the draw-bar, as mentioned by Mr. Halpin. The draw-bar (Figs. 17 and 18), a specimen

Mr. Stroudley. of which was exhibited, was the unbreakable draw-bar designed by the Author for wagons. With respect to the system of electric lighting, which had been adopted on some of the trains for some years past, a Pullman train had been running between Victoria and Brighton, lighted by incandescent lamps supplied by accumulators; the accumulators being charged, whilst the train was at rest, from a dynamo-machine driven by a gas-engine. Although this system answered very well for a particular train, it was not such as could be generally adopted, as the difficulty of placing the trains in certain positions, and for a given length of time, to recharge the accumulators, would be too great. Therefore, in conjunction with Mr. Houghton, the company's electrical engineer, he had devised a system by which the dynamo was placed in the brake van, with a sufficient number of accumulators to give the necessary store of electricity; so that the lamps would continue to burn when the train was at rest. The dynamo-machine was driven from a countershaft placed under the van, and which was driven by two belts from one of the axles of the wheels. Two belts were arranged by preference to reduce the risk of failure, and a dynamo-machine was also now being made to be driven by two separate belts in the same manner as a blowing fan or centrifugal pump. This would reduce the risk of failure of the belts to a minimum. It was necessary to provide an arrangement to prevent the current running back out of the accumulators when the motion of the train was arrested, or reduced below a certain velocity; and an apparatus, similar in principle to his speed indicator, had been applied to make and break contact at the proper time. The connections to the lamps were made so that they could be switched off by the guard when not required; and it was arranged that when the dynamo was not generating a sufficient current, the lamps were supplied from the accumulators. A very simple contrivance was provided for reversing the brushes, and little or no trouble was given by this machinery. A simple apparatus, similar to that which was used for moving the cross-slide of a planing machine, was also provided for tightening the driving-straps, by moving the countershaft in a diagonal direction, so as to tighten all the straps at one time. Two feeding screws, geared together by worm wheels, kept the parallelism of this countershaft exact. The wires were passed by preference along the top of the carriages in a piece of timber having two grooves, one for each wire; and each carriage was supplied with two lamps, each lamp having separate connections, so that the breakage of one lamp would not interfere with the working of the other.

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To enable the carriages to be readily separated from and attached to the train, he had designed a simple coupling, one part consisting of a conical cylinder and a plug, similar to an ordinary stop-cock, the cylinder being attached to the one wire, and the plug to the other. This enabled the carriages to be coupled, no matter which ends came together. These couplings were held together by means of four clips or springs which, after the plug was pushed into position, retained it there; but would yield and allow it to escape should the porters forget to uncouple them when shunting or moving the carriages: thus, the arrangement as carried out did not introduce any difficulty or parts that the ordinary porters could not understand. The exact cost of the maintenance of this apparatus could hardly be ascertained at present; but it was in his opinion certainly less than that of oil lamps, whilst the light was sufficient and of a very satisfactory character. As the brake vans were uniform, this arrangement could be carried out so that any one part would fit the other, and any van or coach would fit together just in the same way as with the ordinary screw-couplings and buffers. This offered many advantages, as compared with the stationary arrangement. In the experiments given of the work performed in running a train between Brighton and London, the power required to work the Westinghouse brake, and also to drive the dynamo-machine for the electric light, was included, although no note was taken of it; and as the consumption of fuel was remarkably low, the additional amount of power necessary to work this apparatus did not appear in figures. In reply to Mr. C. D. Fox, he considered it of great advantage to keep separate engines for the drivers. He had always believed that if an engine was made as carefully as possible, it would respond to the attention that it got afterwards; that the driver would be proud of its appearance, and of the duty he could get out of it: and doubly proud to be able to perform a great duty with a small amount of expense. It was found that the same man would not take the same care of another engine, should he have to work one for a time, as he did of his own; and those engines which had unfortunately to be entrusted to several drivers deteriorated in quality, consumed more coal, and got dirty and out of repair much more rapidly than those which were appropriated to particular men. He was of opinion that it was better for a railway company to spend more capital, and have more engines, so that one locomotive could be retained for each driver, as the total cost for stores and maintenance would in that case be less. In the statement as to the evaporation of water, the amount returned by the exhaust-steam to the tender

Mr. Stroudley. was included in the 13·1 lbs. referred to by Mr. Druitt Halpin, and also in all the statements as to evaporation. Reference had been made by some of the speakers to the practice mentioned by the Author as being now universally applied. That was no doubt correct; but it was not so when the Author commenced the work referred to, some twenty years ago, when, he believed, he stood alone in most of the changes from the old practice. He might mention that the coal consumption per engine-mile for the whole of the engines on the London, Brighton, and South Coast Railway, during the half year ending the 30th of June, 1885, was 28·92 lbs., with the same average load as in the corresponding half year of 1884, namely, twelve vehicles.

Correspondence.

Mr. Burnett. Mr. R. H. Burnett observed that many points were named in this Paper which were very old in the practice of leading locomotive builders; as for instance, the rule for balancing the revolving and reciprocating parts; the boring and turning of the angle-iron rings for attaching the barrel of the boiler to the smoke-box tube plate; the mode described for uniting the seams of the barrel by butt joints and double-lap plates, and double rows of rivets; the mode of constructing the dome seating or base; the use of oblong holes in the suspension links between the top of the copper fire-box and crown plate; the omission of ferrules from the tubes at the smoke-box end; the method described for welding up the bosses of the wheels; and many other details. Several points named by the Author were, however, of great interest and gave great value to the Paper as a record of good locomotive practice.

One of the more important matters referred to was the use of coupled wheels as guiding wheels. He thought the question of their safety as compared with smaller wheels might be left out of consideration as involving little difference one way or another; but as a matter of economical working it was of much importance. The Author referred to the tendency of the flanges of the leading wheels to be forced against the outside rail of a curve, which he considered due to the influence of the weight on the trailing wheels. It was partly due to this, but more so to the draught of the train on the tail of the engine, as was well known. On lines where the curves were sharp and the inclines steep, giving a heavy draught on the tail, or hind end of the engine, the wear of the flanges of the leading wheels was very rapid, entailing great

expenditure and waste of material on the tread of the tire, in turning it up to restore the flange to its proper form and thickness, and the same had to be done to the other coupled wheels. His experience on the government railways of New South Wales, where there were on the main lines many miles of curves of 8-chains radius with long gradients of 1 in 30, was that uncoupled wheels, fitted to a bogie to place them tangential to the rail, were essential to economy in the maintenance of tires. The comparatively easy curves and gradients of the Brighton line no doubt rendered the use of coupled wheels as guiding ones possible without serious inconvenience, or cost for tires. On the railways of New South Wales the standard type of goods engines was for many years a six-wheeled coupled inside-cylinder engine; the cylinders being 18 inches in diameter with 24 inches stroke, and driving wheels of 4 feet diameter, with a wheel base of only 11 feet 3 inches, placed under the barrel of the boilers, so as to make them suitable for the sharp curves of 8-chains radius. The wear of the flanges of the leading wheels was found to be very rapid, involving the frequent turning down of the tread of all the six coupled wheels and great waste of material and labour. The breakage of crank-axles was also frequent. To remedy the wear of the leading tires he introduced engines with a pair of leading wheels of 2 feet 9 inches diameter, in addition to the six-coupled wheels, working in a bogie with a radial arm, as in the Bissell bogie, but with side springs to guide it in a central position in place of inclined planes. The introduction of this additional pair of wheels in front enabled the coupled wheels to be moved more to the hind end of the engine than formerly. By this means the overhanging tail of the engine was shortened, and the effect on the leading wheels by the cross-draught of the train in going round sharp curves was lessened, and the wear of the leading flange greatly diminished, whilst the little flange wear that remained could readily be met by turning up the leading wheels, not touching the coupled wheels. The cylinders were brought outside, and the expensive crank-axle was avoided; the introduction of the additional pair of wheels also enabled the fire-box and boiler to be increased in size without unduly loading any of the wheels—the grate-area being increased from 14 to 20·8 square feet, and the heating surface of the fire-box increased in proportion. The effect of these changes in securing ease in going round curves and in economy as regarded wear and tear, and also fuel, by admitting of an enlarged blast pipe, was most satisfactory. Mr. Burnett.

The Author ascribed the breaking of the crank-axle to the

Mr. Burnett. piston-strains. No doubt that was so when the "big end" of the connecting rod was allowed to wear slack and to "knock," but he was inclined to think that the shocks and strains in running at high speeds over bad joints, and frequently reversing sharp curves, had more to do with it, and that the thinning down of the flanges which had long been resorted to, only partially met the case. Crank-axles of the dimensions usually employed in locomotives would not break, if used in stationary engines with the same dimensions of cylinders and equal steam-pressure. An important point in guarding against breakage of steel crank-axles was the use of large curves in the corners, as compared with what was common with wrought-iron cranks. With steel cranks the corners of the connecting-rod bearing should not be less than $\frac{3}{4}$ inch.

It might be left to the "oldest and best firms in the country" to meet the charge that "attention has not been given to the working out of details;" a statement apparently based on the fact of the Author having found an engine with 17-inch cylinders which gave $1\frac{1}{2}$ square inch section at one part of the piston and crank connections, and as much as 9 or 10 square inches at another part. The Author surely did not mean to say that the connections were not properly proportioned unless there was an exact uniformity of section throughout; or, again, that any locomotive builder of standing made the connections of a 17-inch cylinder with as little as $1\frac{1}{2}$ square inch of section to take the piston strain, which, with that size of cylinder and 140 lbs. steam-pressure, was equal to 14 tons. The Author no doubt alluded to the section of the cotter in the piston-rod cross-head. If so, it should be remembered that it was subject to a shearing action at two points, and its section must therefore be multiplied by 2. With the size of cotter which would be used in that case, the section would be as near as possible 1·5 square inch, and that doubled was 3 square inches. This gave a strain of 4·73 tons per square inch, which was not excessive with the elastic force given out by a piston under steam-pressure.

The Author was judicious in making the axle-boxes amply strong, and with plenty of wearing surface. Riveting by hand, however, in place of by steam or hydraulic pressure could not be commended. The use of deep foundation-rings for the fire-box was a good feature, as also the space of 2 inches between the roof of the copper-box and the roof-bars. The sloping of the roof of the copper-box towards the back was unnecessary on the inclines on the Brighton line. A slope of 2 inches in a length of 5 feet 6 inches, which was the extreme length of the top of the box, was equal to an incline of 1 in 33. On inclines of 1 in 30, on the New

South Wales railways, no inconvenience was experienced with level-topped boxes. Besides, inclines did not always lie in one direction, and so what might be right for a journey in one direction was wrong for another. Mr. Burnett.

The placing of the copper stays far from the corners of the box was a most important point in boiler construction, as also the use of large radii for the corners. More fire-boxes had been ruined by small corners, and by too rigid staying, than by any other cause. He had allowed as much as 8½ inches, measuring from the outside face of the back and front plates, and he had known engines to be constructed with the first row of stays as much as 10¼ inches from the line of the back and front plates. In the case of the engine "Gladstone," the distance seemed to be no less than 12 or 12½ inches. The ash-pan arrangement appeared good for arresting and extinguishing cinders, and it was worth knowing that the spark trouble from the chimney had been, apparently, entirely met by the simple means described. The bending of the tubes was a questionable expedient. There was great risk of their being fixed out of parallel with each other, and therefore more or less in contact. The making of the piston-rod and cross-head in one piece got rid of the weakening effect of the cotter in the older mode of construction. It was rendered easily attainable of recent years by the improved and more reliable quality of cast steel. Slide-bars as used by the Author gave strength with lightness, but they afforded no means of taking up wear and "slack," which occurred even with the best regulated arrangements of parts and surfaces.

The eccentric and strap adopted by the Author were notable as having ample wearing surfaces; but they could not be called "light for their power." The use of thick rims for the wheels was no doubt an important matter in preventing the breakage of tires when they wore thin. The pressure used in forcing an axle into a wheel should be in proportion of the square of the diameter of the axle, and not directly as the diameter, because the strength of an axle was as the square of the diameter, and the strength of the boss of the wheel should be in proportion thereto. The rule he had for a long time adopted was to use a force equal to 1½ ton multiplied into the square of the diameter in inches. For an 8-inch axle it would be $64 \times 1\frac{1}{2} = 96$ tons, the same as by the Author's rule of the diameter multiplied by 12. But for a 6-inch axle Mr. Burnett's rule gave less than the Author's, and he thought properly so. For a 6-inch axle his rule was $6^2 = 36 \times 1\frac{1}{2} = 54$. The Author's rule was $6 \times 12 = 72$. The Author was bold in dispensing with keys in the axles of coupled wheels.

Mr. Burnett. Mr. Burnett had long dispensed with them in uncoupled wheels for carriages and wagons, the key being so objectionable in diminishing the strength of the boss.

It would be interesting to know how the delicate measurements of the vacuum at the various points of the engine were determined, and there were curious anomalies in regard to the steam-pressures in the boiler and steam-chest, given in Tables VII. and VIII.

	In the Boiler.	In the Steam-Chest
	Lbs.	Lbs.
With a speed of 20 miles per hour, there was—	140	135
„ „ 45 „ „	140	135
„ „ 55 „ „	135	135

Again, Table VIII. gave 13·1 lbs. of water evaporated per 1 lb. of coal. That was certainly a remarkable result, and highly important if it could be repeated with any degree of certainty.

Mr. Lapage. Mr. R. H. Lapage observed that the Paper referred to the class of engines constructed to meet the peculiar circumstances of the London, Brighton and South Coast Railway, and no doubt the Author would modify the details to meet the exigencies of other railways.

After about twenty years' practical experience with the locomotive both at home and abroad, it appeared to him that large wheels placed in front in an express locomotive were not so safe as smaller wheels, nor as a properly designed swing bogie, which he preferred to the rigid type of bogie. Although agreeing with the Author concerning the easier running, yet it was obvious that the smaller wheels for leaders were safer on a railway, though producing somewhat more friction than larger wheels. He had been accustomed to work locomotives on roughly constructed railways where a number of cattle strayed on the line, and he had found that engines fitted with coupled leading wheels left the rails, owing to any obstruction or defect in the line, much oftener than engines fitted with bogies in front; in fact experienced drivers would not take upon themselves to run at a high speed with engines working chimney foremost, and having the leading wheels coupled, or with leading bogie tank-engines running backwards. He did not mean to infer that English railways were likely to get into a bad state, but there were times when, after heavy rain, frost, or other mishaps, the permanent way could not be so sound as it should be, and the question was, then, which engine would stick better to the rails, one with a wheel like in the "Gladstone" type, or one with smaller wheels as chiefly used on other railways. It was stated in the

Mr. Lapage. Paper that coal from South Wales was used mixed with Derbyshire coal. This was some of the best class of fuel, and he thought it accounted to a great extent for the complete combustion. He saw no reason why a locomotive, when properly designed and using good fuel and good water, should not work without trouble. No doubt the Author had both good fuel and good water, or else he would not have placed the safety-valves on the top of the dome where the regulator was. Mr. Lapage found this arrangement most objectionable; in the first place, when working up a gradient, the pressure-gauge would show a higher pressure than was blown off at the safety-valves; the reason was that the steam was being used as fast as it was generated, and before the full pressure could reach the safety-valves; in the second place, should it be necessary to shut off steam for a moment, the safety-valves began to roar, just in the most sensitive part of the boiler, and on attempting to open the regulator priming would commence, and the train would stop if ascending a steep incline. Pressure had to be reduced before the regulator could be effectively used, and this was no easy matter, especially with a large wood fire. He had known trains lose many hours through having the safety-valves on the dome where the regulator was. On a railway where he was Locomotive Superintendent about twelve years ago, he removed the safety-valves off the dome with most favourable results; the railway had long gradients varying up to 1 in 80, and the trains ran down inclines for about 30 kilometres at one stretch without steam. Again, on a railway with which he was now connected there was one length of 64 kilometres, having gradients from. 1 in 60, which were traversed without steam and such of the engines as had the safety-valves on the dome where the regulator was, gave trouble. He mentioned these distances for the purpose of showing that it must be pretty hard work to get up such long inclines, and it was absolutely necessary that the regulator should be efficient. It appeared to him that priming was the inevitable result of such a combination of dome, regulator and safety-valves, even in England where there was good water. With regard to the position of the regulator, he found it was better to place it in the smoke-box when pure water could not be obtained, as the regulator could be lubricated when necessary, and also the steam could be taken from different parts of the boiler, either by having two small domes and a steam pipe running longitudinally through the boiler with branch pipes to these domes, or without domes, using merely a longitudinal steam pipe with a number of properly distributed small branch pipes arranged suitably. The Author referrèd to the difficulty he had

Mr. Lapage. experienced with the "direct stay" for supporting the fire-box roof, owing to the cracking of the upper flange of the tube plate and between the tubes. He also had experienced a similar difficulty; after trying various methods he came to the conclusion that the best remedy was to make the first row of stays with a small slot, and to allow the copper fire-box to expand upwards; this would obviate the trouble.

It had been almost always customary on the Continent, and mostly in America, to build locomotives with the rigid stay, but it would be noticed that they placed the first row of stays well back from the tube-plate, to allow for expansion. He did not, however, wish to advocate this method, but on the contrary preferred the bridge system. In fact the company with which he was connected had been lately getting some engines built on the continent, and had difficulty in persuading the makers of the utility and advantage of the bridge bars. He might state, however, that several engines constructed on the continent had rigid roof stays, and the boilers were working satisfactorily.

With regard to fixing the boiler tubes, he advocated as much surface as possible through the fire-box tube-plate to make a good bearing for the ferule, and the tube-plate to be 1-inch thick where the tubes passed, taking the sharp edges off the plates; at the smoke-box end, he preferred merely to roll them with a dudgeon roller, letting the tubes stand out about $\frac{1}{4}$ inch, and to use no ferules; by this means the tubes were allowed to expand a little, if necessary. He had found brass tubes put in in this manner stand better than those flanged over at both ends.

Mr. Mair. Mr. J. G. Mair remarked that the statistics relative to the trials given in the Appendix to the Paper were of great interest. It was to be regretted that the nature of the Brighton line prevented their being made of a sufficiently long duration to eliminate the error that must exist in estimating the state of the fires at the commencement and at the end of each trial. It would be seen from Tables II., VII., and VIII., that the average evaporation, per lb. of fuel burnt, was 12·4 lbs. of feed-water, and as this had been taken from the tender and pumped in against a pressure of about 140 lbs. per square inch, it was equivalent to 14·3 lbs. evaporated from and at 212°, or so near the absolute value of the fuel itself, that, on the assumption the experimental data were correct, a very large amount of priming must have occurred. Taking 12·5 lbs. from and at 212° as the maximum evaporation practically obtainable with best Welsh coal, a very simple calculation showed that the priming could not be less than 16 per cent. This might be

the reason why such abnormally high results were obtained; or what was still more likely, the shortness of the experiments prevented the data from being correct. Mr. Mair.

Mr. W. H. Mills observed that the details of the engines described in the Paper proved that much care and study had been bestowed in making all the working parts suitable for the duty they had to perform. There were, however, in the general design of the engines, features differing so much from the arrangements now adopted on many lines, that they naturally suggested consideration and enquiry. It would be instructive to have a little more information about the reasons which induced the Author to adopt inside cylinders in preference to outside cylinders for the engines on the London and Brighton Railway. The Author's experience of both classes, and particularly with the outside-cylinder engines on the sharp curves and heavy gradients of the Highland Railway, must have afforded him valuable information. Mr. Mills.

The increasing speeds and weights of fast passenger trains necessitated stronger and heavier engines, and if the inside-cylinder arrangement was adopted, the task of placing the cylinders and other working parts inside the narrow width of framing, would become far from an easy one. The larger cylinders required larger cranks, and consequently left less space for the remainder of the machinery. With the larger cranks and the heavier strains, it was questionable whether the crank-axles of modern locomotives were relatively as strong in proportion as were those of lighter and smaller engines in use some ten years ago. Even at the best, the life of a crank-axle was but a short one, and therefore, in addition to the risk of an accident always contingent on a fracture, there was the repeated outlay in replacing one of the most costly portions of the machine. The Author's method of casting the two cylinders in one piece was excellent, but he admitted that the crank-axle was a disadvantage which belonged to the inside-cylinder engine; and he also admitted that, owing to the narrow gauge of the rails, the crank-axle could not be made so strong as it ought to be. Now, if under these circumstances the crank-axle was a disadvantage, it was difficult to comprehend why the Author adopted the inside- in preference to the outside-cylinder arrangement. Outside cylinders not only dispensed with the disadvantage of the crank-axle, but afforded the designer more freedom to introduce a larger diameter of cylinder, and more convenient and accessible arrangement of the other working machinery. If in addition to the practical utility of the locomotive as a machine, any value was attached to the beauty or symmetry of design, then there

Mr. Mills. would be but few persons who would deny the superior elegance of the outside-cylinder engines on the Great Northern, Caledonian, London and North-Western, Great North of Scotland, and Highland Railways, as compared with any of the inside-cylinder engines in the country.

It was a subject of considerable surprise to many that the Author had not adopted the four-wheel bogie-truck for his latest-designed passenger engines. It was a matter of experience that the increased speed, and heavier weight of modern locomotives, necessitated greater length of engine, not only as a carrying-machine, or distributor of the weight, but for steadiness on the road, and it was under these circumstances that the bogie-truck was of especial value. By its aid a largely-extended wheel-base could be obtained, combined with a capability of lateral movement for the facility of traversing sharp curves. The introduction of the bogie-truck on so many of the railways in Great Britain, and the increasing number on those lines, would indicate that the principle had been acknowledged and appreciated. The excellent result of the working of the bogie-engines on the Great Northern, Midland, London Chatham and Dover, North British, Great Southern and Western of Ireland, and many other lines, was so well known as to need no comment here, and yet, in the face of all this evidence of recognized merit and utility, it was difficult to understand why the Author had not introduced the bogie in heavy passenger-train engines.

In the United States of America, with its 120,000 miles of railway—or, in other words, with more mileage than all the railways in Europe put together, the outside-cylinder, bogie-truck engine was the only type of locomotive in use; whereas in Great Britain, with only about 20,000 miles of railway, there were but a few lines which as yet had adopted bogie-trucks, or outside-cylinder engines. It would be forcing the argument to assume that those, who were so much in the minority as to mileage, knew better, or had more mechanical wisdom, than the majority. Many engineers had seen, and were aware of, the excellent service performed by the American engines, and at high speeds, and had experienced the advantages of the accessibility of all the working parts, and the benefit of the flexible wheel base on the road. Many were also aware of lines on the continent, and in the colonies, where the stereotyped rigid wheel-base engines had been superseded for the American type of engine, and it was certain that these important changes were not made without some very strong reasons. There were thousands of miles of railway over which the American engine with its bogie, or "path-finder," ran easily

and safely, but on which a rigid wheel-base engine could not be made to keep on the rails. It was true that in those places the permanent way was not up to the standard of excellence customary in great Britain, and that the type of engine had grown out of the special class of work to be done. At the same time it was only reasonable to infer, that the bogie-engine which had so conspicuously proved its advantages on an inferior description of road, would be equally prominent in success on a first-class, well-maintained permanent way. Most engineers who had walked round the curves of important lines in England, would have observed the tiny particles of steel, or iron, scattered alongside the outer rail; silent but truthful evidence of the conflict constantly going on between the tires of the rigid wheel-base engines, and the rails of the permanent way. Whether these shreds of steel were from the rails, or from the tires, or from both, the railway company had to pay for this deterioration. These wearing-away indications also conveyed unpleasantly the conviction that, when running at high speeds round the curved portions of the road, there was, with rigid wheel-base engines, too small a margin of safety. A slightly uneven or worn rail, or a sharp flange on the wheel, might supply all that was wanting to cause the engine to leave the track, and result in terrible loss to life and property. Engineers would be only partially perfecting the locomotive if they merely improved its minor working parts, and left it with inherent defects as a weight-bearing, weight-distributing carriage. The best and most valuable locomotive must be the one which would do its work with the greatest ease and least destruction to itself, and the least detriment to the road over which it had to travel. Mr. Mills.

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10 March, 1885,

EDWARD WOODS, Vice-President;

and 17 March, 1885,

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Paper "On the Construction of Locomotive Engines," by Mr. W. Stroudley, occupied both evenings.

24 March, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2059.*)

"The Electrical Regulation of the Speed of Steam-Engines, and other Motors for Driving Dynamos."

By PETER WILLIAM WILLANS.

THE economy of electrically regulating and reducing the speed of motors driving arc lights in series, as light after light is thrown out of circuit, is so obvious, that the Author does not propose to allude to it in this Paper, further than to show a means by which the regulation can be accomplished.

In incandescent lighting, however, although the steadiness and uniformity of the lights are of the utmost importance, and the difficulty of obtaining them, especially in large installations, is great, the necessity for such a governor is, perhaps, not generally recognized, and it is with the regulation of this system of lighting, that the Author proposes mainly to deal in the present Paper.

If dynamos could be made perfectly self-regulating, and centrifugal governors absolutely isochronous, and if the resistance of copper wire and the friction of the motor could be eliminated, electrical governors would still have distinct advantages in their fewer working parts, their absence of friction, their greater compactness, and their capability for easy and complete adjustment. Until, however, perfection is reached in the machines, and especially until a lower price shall allow electrical engineers to use copper freely in the mains, centrifugal governors will permit and even increase irregularities in the lighting, which will disappear with the use of electrical ones.

The Author will first refer briefly to the causes of these irregularities, and then endeavour to show how they may be prevented.

Dynamos have been so much improved of late, by the use of more powerful field magnets, and the consequent reduction in the

number of turns of wire on the armature, that the resistance of the latter is no longer such a disturbing element as it was; and a good result may now be obtained with a first rate mechanical governor, where the lights are placed in the neighbourhood of the machine. The most economical machine, *i.e.*, the pure shunt, is therefore becoming better and better adapted for small variations in the load, and compound machines are less necessary.

Where, however, the mains are long, and laid with some regard to the value of copper, their resistance becomes a factor which it is impossible to neglect. It may be enough to render the action of the best self-regulating machine (unless specially wound for the circuit) very imperfect, and to increase the error in a shunt machine so as practically to prohibit its use if the motor driving it be mechanically governed.

In many cases, moreover, where motive-power is cheap, as for instance with turbines, it would be desirable, for economical reasons, to lay small mains, and to put up with considerable loss in them, were it not that the regulation of the lighting is then almost impossible without some system of adjusting the speed of the dynamo, so as to maintain a constant electromotive force at the point where the current is used, and not where it is generated.

For any particular circuit, of course the resistance of the leads can be taken into consideration, and a compound dynamo specially wound to suit it. But the difficulty of turning out such dynamos commercially is greatly increased by the special winding of each one, and such a system in a large installation would entail the great drawback, that the dynamo wound for one circuit would probably not be adapted for the others, and the advantages arising from the interchangeableness of the units would be lost in consequence. Neither are the magnetic qualities of the iron used in the magnets so well understood as to admit of absolute calculations being made for each and every machine beforehand.

It must not be forgotten that the error which is introduced by the resistance of the leads is of the same nature as, and is aggravated by, the error in the speed of the motor when regulated by an ordinary centrifugal governor.

Assuming that a machine is perfectly compounded in the first instance, but that the resistance of the leads introduces a loss of 7 per cent. in electromotive force when the maximum number of lights is in use, this loss practically disappearing when the lights are at their minimum, the motor should obviously be so regulated that its speed should increase by nearly 7 per cent. as the lights are turned on. A centrifugal governor would so regulate

the speed of the motor, that instead of increasing it would diminish it, probably to the extent of 5 per cent., and the result would be a serious reduction in the power of each individual light.

Another error, in no way allowed for by mechanical governors, arises from the heating of the machine, and from the consequent reduction in electromotive force at the designed speed. Moreover, however carefully these difficulties are considered at first, changes may subsequently be made in the conducting mains or leads of an installation which will upset the most exact compounding: nor can compound machines overcome the difficulties which arise when two or more independent units are connected to the same mains, and it is desired to control the speed of the several units in such a manner that each does its fair share of work. Most of these difficulties disappear with the use of Electrical Governors, and all are thereby reduced in extent and become less formidable.

It is not with any intention of detracting from the credit due to those who have given so much time and thought to the production of compound or self-regulating machines, that the Author brings forward the merits of Electrical Governors; but rather in the hope of going a step further in the same direction, in order to surmount the remaining difficulties of the problem, and to maintain constant light even if the load be very variable and the mains very long.

It should further be mentioned that while the pure shunt machine is at once the simplest to construct and the most economical theoretically, its combination with a motor electrically governed ensures a reduction in speed, and consequently in the losses due to the frictional resistances of the motor, when the lights are not at their maximum. Assuming the variation in speed to reach 15 per cent., as it easily may, the gain due to a corresponding reduction in friction is by no means to be despised, remembering, that in a well-designed installation, it should not be the rule at all times to drive engines and machines at full power.

The Author has thought it advisable to point out his difficulties, which are doubtless familiar to many who have had practical acquaintance with the subject, before proceeding to the description of the governors themselves, the more so as many of the early Electrical Governors appear to have been designed with a view to the maintenance of a constant speed of engine, and, especially as none of these governors have had, so far as the Author has been able to ascertain, any extended practical application.

The earliest allusion to the electrical regulation of motors

driving dynamos, of which the Author is aware, is in Mr. St. George Lane Fox's specification, No. 4,626, 1878.

Within a few days of the date of the above, a patent (No. 4,705, 1878) was taken out in this country by Messrs. Sawyer and Man, of the United States of America. In their specification they describe a cog-bar of T section, arranged to slide in a groove cut in a piece of metal; this piece of metal is pivoted on a standard, and so arranged that, when it is tipped one way or the other, the cog-bar comes into gear with one or other of two pinion-wheels. The wheels are kept constantly revolving in opposite directions, and the cog-bar moves in one direction or the other, according to the direction of rotation of the pinion-wheel with which it is brought into gear for the time being, and it is connected to the steam-valve of the motor. The tipping of the cog-bar is controlled by an electro-magnet placed in the circuit, and this magnet is opposed by a spring, so that when the magnet is overpowered by the spring, the cog-bar is brought into gear with one revolving pinion, and the steam-valve is opened wider, and when the spring is overpowered by the magnet, the cog-bar is brought into gear with the other pinion, and the steam-valve is closed.

In the following year, 1879, Mr. J. D. F. Andrews, in his specification No. 2,321, describes the use of a solenoid for the purpose of regulating the speed of the motor. In this method the coils of the dynamo are wound with separate parallel wires, and an arrangement is effected by which a greater or less number of these wires may be coupled in series, he says—

"According to another method, when the coils of the machine do not consist of separate parallel wires, I introduce into the external circuit a solenoid having an iron core, which is connected to a throttle or other regulating valve of the engine that works the machine, in such a manner, that according as the strength of the electrical current passing through the solenoid is greater or less, the core is caused to move more or less by its attraction, and so, by moving the valve, to regulate the speed of the engine and machine. Instead of applying this apparatus directly to the regulating valve of the engine, it may be applied to vary the outlet of a fluid pumped by the engine, to act on a piston connected to the regulating valve."

Although nothing further is said about this in his final specification, it is obvious that Mr. Andrews had in contemplation a governor similar to that patented by Mr. Richardson two years later. The Author believes that Mr. Andrews was the first to suggest the use of a fluid relay for actuating the regulating

mechanism so as to leave to the solenoid only the duty of working the valve of the relay cylinder.

In 1881, Mr. John Richardson obtained a patent—No. 288—for an invention "relating to an improved method of, and appliances for, controlling and regulating the speeds of engines employed for driving dynamo-electric machines, which have to be driven at an absolutely uniform speed."

The first governor described in this patent was an ordinary centrifugal one, driven by an electromotor.

The following is Mr. Richardson's description of the action of the apparatus:—

"This electromotor is actuated by a portion of the main current which produces the electric light, and its speed varies in relation to the intensity of the said current, so that when the large dynamo-machine which produces the current has reached such a speed as gives the required intensity, the governors at the same time attain sufficient speed to shut off all further admission of steam, and the current is therefore retained exactly at this intensity, and as all changes of intensity, however minute, instantaneously affect the admission of steam, whatever may be the variations of intensity in the current, these are instantaneously rectified by a greater or less admission of steam, thus maintaining the current at a practically uniform intensity."

Mr. Richardson goes on to describe an electro-magnet which falls in the event of the current entirely failing, its weight being such as to overpower the centrifugal governor.

According to another method of governing, by Mr. Richardson, the centrifugal governor is entirely dispensed with. The stalk of of an equilibrium-valve passes through the valve-casing, and is connected to the core or armature of an electro-magnet placed below. Mr. Richardson says, "When the current passes through the electro-magnet this armature is attracted downwards so as to partially close the admission of steam, and the position of the throttle valve and consequently the admission of steam is regulated according to the intensity of the electro-magnet."

"The throttle-valve is made of such area that its vertical motion need not be more than a fraction of an inch to give all the variations required from the full power of the engine to an absolute cut-off of the steam."

In another governor, the core of the electro-magnet acts on a lever connected with, instead of directly to, the throttle-valve.

In 1881 Mr. C. A. Carus-Wilson obtained a patent, No. 568, for various combinations of electro-magnets with speed-governors,

the duty of the electro-magnets being to supplement the action of the centrifugal governor.

Towards the end of the same year, Mr. George Westinghouse obtained a patent, No. 3,409, for an electrical regulator, consisting of a solenoid and a fluid relay, similar in principle to that of Mr. Andrews. The core of the solenoid was attached to a balanced valve, which admitted or released fluid under pressure to or from a cylinder in which was a piston, connected by a rod to the regulating valve of the motor. The fluid under pressure was admitted to the cylinder when the current through the coils of the solenoid was greater than desired. When, on the other hand, it fell below the standard, the fluid was allowed to escape, the relay-piston being brought back by a spring. A small rotary pump, driven from the engine, is shown as a means of obtaining the requisite fluid-pressure.

Probably the friction of the stuffing-boxes was found troublesome in the two governors already alluded to, as in the following year Mr. Richardson took out a patent, No. 941, 1882, for further improvements. After mentioning a governor described in his previous patent, in which a great part, or the whole, of the electric current passes through the governing solenoid, he says— "According to my present invention I connect this solenoid with the valve by fixing the levers under instead of above the valve, to draw the valve downwards instead of forcing it down, and thus get the stalk of the valve in tension instead of compression. By this means its diameter, and therefore its friction in the stuffing-boxes, is very much reduced. This thin stalk I make of steel or of phosphor-bronze, and carry it upwards through the stuffing-box, connecting its upper end by means of a flexible cord or steel band either to the arm of a lever upon the long arm of which I hang a weight, or pass it round a pulley on the opposite side of which I hang a weight, or connect it directly to a strong spiral or other spring, the object being to lift the valve upwards to open it in opposition to the force of the solenoid tending to close it."

In the same specification he mentions a method of winding the solenoid in such a manner that by moving a lever over certain contact-pieces "the solenoid can be varied in intensity, each additional contact-piece bringing into play, or shutting out, an additional coil of wire, thus permitting the speed of the engine to be varied at will according to the work it is set to do." The lever referred to, which is used for varying the speed of the engine, is described and shown as if it were worked by hand, not automatically.

"With currents of lower intensity," Mr. Richardson proposed to use two solenoids placed side by side, through the coils of which "the current could be caused to pass either in series or parallel currents according to circumstances, and the intensity of which can be varied by moving the levers over the contact-pieces as previously described." Mr. Richardson also describes an elastic double diaphragm inserted between two parts of the throttle-valve spindle. Steam from the boiler enters between the two diaphragms by a flexible pipe, so that when the pressure of steam in the boiler increases the throttle-valve spindle lengthens, and so compensates for the increased boiler-pressure. "Could a uniform pressure of steam be depended upon, such an arrangement would be unnecessary in this class of governor, but, as it is well known that boiler pressures do vary considerably, this expedient is used to counteract the same, which it does by the diaphragm expanding and thus partly closing the valve as the pressure rises, and contracting and thus admitting more steam to the engine as the pressure falls." Mr. Richardson further describes a governor in which the core of a solenoid is directly connected to one end of the valve-rod in a well-known arrangement of automatic expansion-gear, for the purpose of varying the point at which the steam is cut off.

The Author is not aware how far any of these methods have been applied practically, but it would be interesting to learn what is the experience with governors of this class, particularly as to the amount of power absorbed in the solenoid, and as to the accuracy of the governing. From his own experience, the Author would have supposed that the direct actuation of the expansion-gear by an electro-magnet was impracticable with any form of magnet which could be economically employed.

In 1883 Mr. Richardson introduced a centrifugal governor, which, on any alteration in the speed of the engine, completes the circuit through an electromotor in one direction or the other, the duty of the motor being to vary the position of the expansion gear.

The governors, to which the Author has alluded, may be divided into three classes: 1st. Those in which an electro-magnet, or an electro-motor, is used, in conjunction with an ordinary centrifugal governor. 2nd. Those in which the armature of an electro-magnet (the coils of which form part of the circuit to be governed) is connected directly to the regulating valve of the engine. 3rd. Those in which an intermediate relay of power is used to increase the power of the electro-magnet. Governors of the first class are necessarily complicated, and combine some of the dis-

advantages both of electrical and of mechanical governors. Those of the second class are, in the Author's opinion, not powerful enough to be depended upon unless very large magnets are used, and considerable power is absorbed in them. It may be well to point out that, when the solenoid core is directly connected to the throttle-valve or expansion-gear, the power available for regulation is not the total attractive force of the coils, but only such an increase or diminution in that force as results from a change in the electromotive force, so small as to be unobjectionable in the lights. It is impossible to avoid friction in the stuffing-boxes, especially when high-pressure steam is used, and half a turn of a nut by a careless man may spoil the lighting, unless there be ample power in reserve.

Governors of the third class, although they have the requisite power to move the regulating mechanism, have not the necessary control over it, on account of the independent action of the parts of the relay. It is evident that, in a governor of this class, each change in the load must entail a double motion of the valve of the relay, or of the part which, in an electrical relay, takes the place of the valve. If the current through the coils increases, the movement of the core calls the relay mechanism into action; and that action continues until the core has returned to its old position. By that time the regulating mechanism may have moved rather too far, and the action described above is repeated, but in the reverse direction. Thus the solenoid core and the regulating-valve of the engine move independently of each other, and it may often happen that while the core of the solenoid is moving in a direction to close the valve, the valve is opening. This independent action must introduce serious irregularities in the lighting, the extent and duration of which will depend on the weight and the speed of the revolving parts of the machinery, as also upon the time it takes for a change in the speed of the dynamo to affect the position of the core of the solenoid. The core of the solenoid may be moved almost instantly when the change in the load takes place, but it may not move back for a considerable interval of time, and during that time the action of the relay mechanism must continue. For these reasons, apparently, Electrical Governors, the need for which has long been recognized, and which were first suggested seven years ago, have until recently only been applied in isolated and experimental instances. Evidently some means are required to ensure the simultaneous action of the core or armature of the electro-magnet, and of the mechanism which actuates the throttle-valve.

In a more recent form of governor designed by Mr. Jamieson,[1] the Author would have expected to find that the friction of the mechanism caused irregularities in the lighting, unless very powerful magnets were employed and considerable power was absorbed in the governor; and he was surprised that Mr. Jamieson insisted on the necessity for a self-regulating dynamo. True, the question was one of lighting ships by electricity, where the error due to the leads is not likely to be so great as on land; and in that class of work the difference in speed which their resistance and that of the armature would otherwise necessitate can be compensated for in winding the magnets with something like certainty. But where electrical regulators are employed it is unnecessary absolutely to fix the speed of the dynamo beforehand.

The Author thinks that the governor mentioned by Mr. Jamieson, which permitted the speed of a Westinghouse engine to increase 25 per cent. must have been an exceptionally bad one. He has made mechanical governors which would control the speed of quick-running engines within 5 per cent.; and there are well-authenticated cases of the normal speed being maintained within 2 per cent. in large engines, but it so happens that for electric lighting constant speed is not usually wanted.

The principal worker at this problem in America has been Mr. Hiram S. Maxim, well known in this country for his new gun, and he has very kindly sent to the Author an account of what he did, from which the following are extracts:—

"In the summer of 1877 I made an electrical governor for controlling the speed of the steam-engine which operated the dynamo-electric machines. This governor operated on the following plan: A powerful electro-magnet, having pole extensions made to fit a copper cylinder or disk, was mounted on an oscillating shaft. This was mounted upon a stand with an arm projecting. This projecting arm controlled the point of cut-off on a Corliss engine in one model made.

"In another model this projecting lever was made to actuate a device which would open and shut the throttle-valve after the manner in which the governor operates on the gates of a large water-wheel; that is, it operated a clutch which determined which way the screw was turned.

"The copper armature was made to rotate at a high velocity between the poles of this electro-magnet and at a constant speed,

[1] Minutes of Proceedings Inst. C.E. vol. lxxix. p. 8.

the electro-magnet being wound with fine wire and connected in multiple arc, the same as the lamps were connected. Of course as the current became too strong the tendency of the copper was to rotate the magnet in the same direction.

"This was opposed by a spring. If the spring was stronger than the tendency of the magnet to rotate with the copper more steam was let on to the engine; if the tendency to rotate was greater than the stress of the spring, then the movement of the projecting arm was such as to partially close the steam off from the engine.

"By reference to a drawing on page 31 of 'Engineering, Jan. 9th, 1885, you will see a regulator which operates practically upon the same principle which mine did. It, however, has the addition of some bevel gears for reversing the motion."

Another of Mr. Maxim's governors was described by him in a letter written to the Editor of 'Engineering,' and published in that journal on March 4th, 1884.

The Author cannot claim, either for himself or for those who have worked with him, an absolute priority in their recognition of the advantages to be expected from this method of governing; but so far as he is aware, he has been the first to make a practical success of it, his method having been adopted in fifty-three instances. His attention was first called to the subject about three years ago by Mr. R. E. Crompton, who mentioned the great need of an Electrical Governor in the case of arc lighting in series, so that the resistance which it was necessary to insert when lamps were switched off could be dispensed with, and economy thereby gained.

As the action of a solenoid or electro-magnet is obviously too delicate, except in very small engines where the power absorbed is not considered, to admit of its direct application for regulating the position of a throttle-valve, the Author suggested that it would be desirable to use, for the actual work to be performed, some relay of power, such as steam or water under pressure in a cylinder, the duty of the governing solenoid being merely to actuate a piston, or other equilibrium valve controlling the supply and discharge of the fluid under pressure. He also suggested that, as the independent action of the piston-valve and piston would inevitably lead to hunting, they should be connected with the regulating solenoid in such manner that the action of the latter on the piston-valve should be neutralized by the motion of the throttle-valve, as the steersman's action is neutralized by the motion of the mechanism connected with the rudder in Mr. M'Farlane Gray's steam-steering apparatus.

He accordingly designed and made the governor shown in Plate 9, Fig. 1. The main principles embodied in this governor have not been subsequently modified, although the details have only been decided after tedious and numerous experiments.

By a coincidence Mr. Wilson Hartnell arrived independently at conclusions very similar to those of the Author; and he showed his designs to Mr. Crompton at about the time the Author's first governor was ready for trial.

Subsequent inventions have been introduced, one by the Author, for the use of electrical relays; and one in the joint names of Hartnell, Willans and Crompton, this latter including some important modifications of Mr. Hartnell's, by which the use of steam as a relay is facilitated; also several methods of winding the solenoid, suggested by Mr. Crompton, in order to compensate for the loss in electromotive force due to the resistance of the leads, without its being necessary to lead the solenoid circuit to the lighting centre. The Author has also introduced a safety arrangement, and a combined potential and current governor, which will presently be described.

So far the relay employed has been water under a pressure of from 10 to 20 lbs. per square inch. The use of water has the advantage of simplicity, and dispenses with stuffing-boxes, which would be necessary if steam were employed. Since the pressure required is not great, nor the quantity of water large, and as, moreover, it may in most cases after passing through the governor be used as feed-water for the boiler, it will probably be employed oftener than the other relays named. About 30 lbs. of water per hour are used in the governor of a 60 HP. engine.

Messrs. Willans and Robinson were on the point of adopting the electric light when the Author's first patent was taken out, and he carried out all the experiments connected with the governor at their factory; but it was Mr. Crompton's recognition of the necessity for a regulator which would act from a distance, which first directed the Author's attention to the subject, and afterwards induced him to persevere with the experiments in spite of practical difficulties.

Throughout these experiments he endeavoured to keep the following points in view:—

1st. The necessity for very prompt action and even greater sensitiveness than is required in a governor for constant speed; for an increase in the current through the solenoid is often the first indication to the governor that the speed of the motor requires not merely to be brought back to a standard, but to be reduced.

2nd. The necessity for great power in the relay, combined with the minimum of friction in the electric regulating portion of the mechanism.

3rd. The power to control the potential automatically at any desired point in an incandescent installation, and not merely in the engine-room, as in the case of mechanical governors.

4th. The power so to regulate the speed of two or more units of an installation, that the work is properly divided between them.

5th. The easy and accurate adjustment of the apparatus while at work so as to avoid any errors due to friction, such as occur in centrifugal governors, in which the revolving balls act on a stationary spring, the tension of which is adjusted at will.

Proceeding now to the diagrams, Plate 9, Fig. 1 represents the experimental governor already alluded to. It was made during the winter of 1882–83, and employed regularly during the following winter for controlling the potential for one hundred incandescent lights at Messrs. Willans and Robinson's works at Thames Ditton. In this governor the core Q is attracted by the coils of the solenoid S, and this attraction is balanced by the spiral spring X, from which the core is suspended by the rod R; on the rod R is a washer Y; against this washer a roller A presses. This roller is carried on the end of a differential lever A B C, the lever being prolonged in order to carry a balance weight Z, which can be regulated in such a manner that the roller A presses more or less on the washer Y. The point in the lever C is connected to the rod joining the piston in the relay-cylinder W to the throttle-valve T. To the point B is connected the rod of the piston-valve P. If the current through the coils of the solenoid S increases, the core Q is drawn further into them, and the piston-valve P is also moved down. The water under pressure is thus allowed to act on the under side of the water-piston, entering the cylinder by way of the pipe E, the annular space between the two pistons of the piston-valve placing this pipe in communication with the passage K. The water-piston moves up, closing the throttle-valve T, which is shown as a piston working in a perforated cylinder. The water above the water-piston is discharged by the upper of the two pipes F F. As the water-piston moves up, the point C in the differential lever moves up with it, and to a less degree the point B also, the motion continuing until the piston-valve P is brought back to its original position, when the mechanism comes to rest with the throttle-valve in its new position, until some fresh disturbance in the circuit or in the steam-pressure calls it again

into action. The movement of the two points A and C in the lever is practically simultaneous, so that to the observer the point B appears to be a fixed fulcrum on which the lever rocks, the movement necessary to open the passage being very small.

In the experimental governor the point A was not connected rigidly to the rod R, because it was thought desirable to obtain reliable information as to the friction of the piston-valve under ordinary conditions. The weight Z was so regulated that it just overpowered the weight of the roller A, but the slightest increase in friction was shown, whenever more steam was required, by the washer Y leaving the roller as the core moved up, when the spring overpowered the diminished current. By carefully observing the behaviour of different valves the details of the apparatus were determined experimentally, and the friction of the piston-valves was eventually reduced to about $\frac{1}{10}$ oz.

The rod of the piston-valve passed in this case through a bush, H, at the lower end of the valve cylinder, and it was impossible entirely to get rid of the friction of this rod; but in all subsequent governors the piston-valve has been worked from above, the rod passing down a tube of sufficient height to ensure that the water discharged from the relay-cylinders shall not pass over it, thus dispensing with stuffing-boxes (Plate 9, Fig. 2).

The principal difficulty at first encountered was that of "hunting," and many devices were tried to get over it, such as dash-pots to prevent the core moving quickly, and cocks on the water-pipes to cause the relay-piston to move slowly. These devices prevented, to some extent, actual hunting or oscillation of the throttle-valve after a change in the load, but they introduced a worse evil in the slower action of the governor whenever a large change in load necessitated a rapid alteration in the position of the throttle-valve, the result of this slower action being a considerable temporary alteration in the intensity of the lights. It was long before the Author realized the necessity for absolutely simultaneous movement of the regulating mechanism and the relay-piston, and that the dash-pots were only useful so far as they prevented the core of the solenoid from moving more quickly than the relay-piston. Eventually all dash-pots were abandoned, and the hunting was overcome by increasing the area of the passages between the piston-valve and relay-cylinders, so that the throttle-valve could move as quickly as, and as nearly as possible in unison with, the core of the solenoid. Improvements in the piston-valve, whereby its friction was reduced to a minimum, also conduced to similar results; for, as the governor cannot be

called into action until the increase in the current through the solenoid coils is sufficient to move the core and overcome the friction of the valve, any decrease in the friction must render the action of the governor more prompt and delicate.

In this first governor the Author thought it desirable to try the experiment on a small scale, and the relay-cylinder was only 1 inch in diameter. This proved sufficient for the regulation of the engine, the power of which was 15 I.HP., but all subsequent relays have been made much more powerful to provide for contingencies.

Plate 9, Fig. 2 shows the governor ordinarily employed for controlling the position of the throttle-valve. In this type of governor the travel of the core is necessarily the same as that of the relay-piston, and it is not therefore suitable for any but small ranges of position in the regulating mechanism. Otherwise the arrangement is a most convenient one, for the throttle-valve water-cylinder and solenoid are placed one above the other in the same axial line. The friction of joints and pins is avoided, the piston-valve being connected directly to the core of the solenoid. No packing is required on the piston-valve rod as it passes down the tube, H, which is high enough to prevent any splash of water. The piston-valve in this type of governor works inside the hollow rod of the piston in the relay-cylinder. The water enters the annular space between the two pistons of the piston-valve by a port, E, in the side of the cylinder, and a recess, V, in the relay-piston which is made deep on purpose. From this recess the fluid under pressure passes through a drilled hole into the interior of the hollow piston-rod, the position of the hole being such that it is never covered by the valve. The passages leading from the piston-valve to the two ends of the relay-cylinders are so arranged that the relay-piston follows the motion of the piston-valve, and comes to rest when it overtakes it. The passage which is covered and uncovered by the upper piston of the piston-valve leads to the bottom of the relay-cylinder, and the one which is similarly covered and uncovered by the lower piston of the piston-valve leads to the top. If the current through the coils of the solenoid S increases, the core Q is drawn further into them. The piston-valve P moving down allows the water under pressure to pass through the pipe E to the upper side of the relay-piston by the passage K. The relay-piston then moves down until it overtakes the piston-valve P and closes the passage K. The water from the under side of the relay-piston passes away above the upper piston of the piston-valve by the passage K, and afterwards by the flexible pipe M. The core and relay-piston move

practically together, and it requires close observation to see that they are not rigidly connected. The throttle-valve, which is in this case also of the piston type, is double, the ports admitting steam being formed in the side of the sleeve in which the double throttle-valve works.

The diagram shows the valve half-open, the upper piston of the throttle-valve covering one-half of the port. On the slightest increase of current through the solenoid coils the throttle-valve descends, its upper piston closing still further the steam inlet. If, on the other hand, the current decreases, the throttle-valve rises and admits more steam. But should the belt break, or the main lead from the dynamo be severed, so that the current entirely fails, or in case of a short circuit of sufficient magnitude to reduce the difference of potential at the terminals of the machine by 50 per cent. or 60 per cent., the spring draws the core up altogether, and steam is then shut off by the lower piston of the piston-valve.

The governors are usually made with six coils wound with No. 30 wire. When these are coupled six in series they give the necessary pull with an electromotive force of 100 volts; when coupled three in series and two parallel they give the same pull with 50 volts; and when coupled two in series, three parallel, they give the same with 33 volts. The resistance of each coil is about 55 ohms, making 330 ohms when all are in series, and the current due to 100 volts is about 0·3 ampere. The electrical energy absorbed in the solenoid is thus 32 watts, or about one-half that of a twenty candle-power Swan lamp; such a solenoid is capable of controlling with ease the throttle-valve of an engine of 60 I.HP.

The method of winding the six coils separately is very convenient, as it renders the same governor suitable for any electromotive force between 30 and 100 volts, whilst at the same time the cooling surface is increased.

The curve in Plate 9, Fig. 4, shows the pull on the core of the solenoid when the current due to an electromotive force of 100 volts is passing through the coils. The pull is shown by the horizontal ordinates at each ½ inch of the stroke; the attractive force of the coils commences to be felt by the core just before the latter enters them; it reaches its maximum when the core is about half in and half out, and diminishes from that point until it disappears when the centres of the coils and of the core coincide. The part of the travel of the core which is used by choice for regulation is near the apex of the curve. Here the pull is practically constant for a distance equal to the travel required by the throttle-valve, and as the position of the apex of the curve does not differ appreciably

with varying currents, its height, and consequently the mean electromotive force to be maintained, can readily be determined by adjusting the mean pull of the spring by the wing nut at the top. The diagonal line cutting the curve represents the tension of the opposing spring. This diagonal line only coincides with the pull of the spring at one point in the travel of the core.

It is well understood that, in a centrifugal governor, it is not advisable absolutely to balance by the spring at every position the force exerted by the revolving weights, because such perfect balancing would cause "hunting," the parts of the governor influenced by the speed flying off on the slightest change to one end or other of their travel. The same applies in a less degree to the electrical governor. When the core is moved from its position of repose by a change in the intensity of the current through the coils of the solenoid, the spring must do something more than balance the pull due to the normal electromotive force when the core is drawn further into the solenoid, and something less than balance the pull due to the normal electromotive force when the core is allowed by the reduction in current to recede from the coils under the influence of the spring. In other words, as the load is increased there must be a slight fall in electromotive force, and as it is diminished there must be a slight rise in electromotive force. This is shown graphically by the diagonal line representing the tension of the spring crossing the curve representing the pull on the core.

Variations in the tension per inch of elongation of the spring determine the accuracy and stability of the governor; the greater the tension per inch, the more the curves cross and the greater is the stability; the less the tension, the more nearly the curves coincide and the greater is the accuracy. It is obvious that, as the tension of the spring is fixed, the pull on the core must be slightly reduced when the core is at its highest position, and slightly increased when the core is at its lowest; it must, in fact, decrease as the throttle-valve opens, until the opposing forces are balanced at A, and increase as the throttle-valve closes, until they are balanced at B.

The Author has made numerous experiments on various cores, to determine their best proportions for this particular purpose. Obviously the lighter the core the less is the chance of overshooting the mark by its own momentum when sudden changes occur; but on the other hand, it is very undesirable to reduce its section much, for, as the point of saturation is approached, a greater change in electromotive force is necessary to raise the pull due to the normal

electromotive force, and so balance the pull of the spring in the new position of the throttle-valve.

The inside diameter of the coils in the experimental governor was 2½ inches, and the length of the winding of the solenoid was 6 inches. The series of curves in Plate 10, Fig. 10, have been taken at 100 volts, and show the pulls in each position for cores of different lengths but of the same section and extreme diameter. The lengths of the cores varied from 12 inches to 4 inches, the length of the winding being the same in all cases. The maximum pull for each core is shown by the curve Plate 10, Fig. 11; and the percentage of the length of core outside the winding, when the pull is greatest, by Plate 10, Fig. 12. But these curves do not indicate the best results attainable with a given section of core. A core 12 inches long was made of gas-pipe, turned and bored, to remove scale, and to get rid of weight other than that of the iron. This core was tested, and then reduced inch by inch in length, so that the same piece of iron was used throughout the series of experiments shown by the curves, Plate 10, Figs. 10, 11, and 12, and the relative pulls for different lengths of core may be taken as fairly accurate. The curves in Plate 10, Fig. 13, are for cores of varying sections, but all 10 inches long; in Plate 10, Fig. 14, they are for cores of different sections, but of the same diameter and length; they show the maximum pull for varying electromotive forces from 10 volts upwards; with the core eventually decided on, the alterations in pull between 90 volts and 110 volts are proportional as nearly as possible to the square of the current.

As the proportions of the cores were improved, the variation in current through the coils, and consequently in electromotive force, represented by the fall to A and the rise to B (Plate 9, Fig. 4), was reduced. In practice a total range of electromotive force of 2 per cent. to 3 per cent. of the normal has been found sufficient to give stability, and even less than that where the total range of power has not been the total which the throttle-valve allowed. By adjusting the set screws S_1 S_1 (Plate 9, Fig. 2), the position of the coils with relation to the mean position of the core can be readily varied, and by this variation a result is obtained equivalent to the use of a spring of greater or less tension per inch of elongation. That is to say, the two curves do not then cross exactly at the apex. If the coils are moved down, the upper part of the solenoid curve is used, and the curves more nearly coincide; and if the coils are moved up, the lower half is used, and they cross at a greater angle than when they cross at the apex.

Thus the mean electromotive force, and the variations in electro-

motive force throughout the travel of the throttle-valve, can both be adjusted with the greatest nicety; and if the variation in power does not require the whole of the travel of the throttle-valve to be used, that part of the travel usually required can be arranged to be the part in which the governor can regulate most accurately.

In order to give stability to the governor, it is almost always desirable that the curves should cross, but the extent to which they must cross depends mainly upon the suddenness of the changes to be expected in the load. When the angle at which the curves are to cross has been determined, the error in electromotive force at the extremities of the travel of the throttle-valve is in proportion roughly to the length of the travel, and anything which reduces that travel, leaving other things as before, conduces to the accuracy of the governor.

To meet exceptional cases, where it is necessary to use the whole range of power which the travel of the throttle-valve allows, and where at the same time great quickness in action and great accuracy—by which is meant a variation of less, say, than 2 per cent. in electromotive force—are required, the Author has devised a preliminary regulating valve. The duty of this valve is to prevent any great difference of pressure on the two surfaces of the throttle-valve, and to avoid the necessity for that valve moving from one extreme of its stroke to the other. By taking care that, under different loads, the difference in pressure is approximately constant, the travel of the throttle-valve will be very small, and thus accuracy will be gained in the governing without sacrifice of stability. A convenient way of arranging this regulating valve is shown in Plate 9, Fig 5. The Author has shown this valve in connection with the governor in Fig. 1. Steam from the boiler is conducted through the pipe D into a recessed part of the cylindrical casing I, in which is a trunk-piston having holes J J in its sides. This piston is carried by a rod G, which passes through a stuffing-box at the lower end of the casing; on this rod is a washer N, which compresses a spiral spring O, when the piston rises. If the piston rises, the holes J J, moving into the bored part of the casing I, are closed; if the piston descends, they pass further into the recessed part of the casing, and are opened wider. The upper end of the casing I is connected by a small pipe U with the engine side of the throttle-valve of the electric governor. The lower end of the casing I forms part of the steam-pipe from the boiler to the engine; a pipe L connects it with the throttle-valve of the electric governor. The tension of the spring O determines the excess-pressure of the steam outside the electric

governor over that in the steam-chest, or engine side of the governor. If the excess of pressure is greater than desirable, the piston in the casing I moves up and reduces it by closing the holes J J.

Where two or more units in an installation work independent circuits, but all receive steam from one boiler; and where one unit may need the full boiler-pressure at the same time that others require a comparatively low one, the advantage of employing a valve of this kind on the pipe leading to the motor of each unit is very great, for it entirely obviates the necessity for accuracy in the boiler-pressure, the only consideration then being a sufficient pressure for the unit which has at the time the heaviest load. The balancing valve, as it may be termed, serves as a rough preliminary governor, the actual electrical governor putting the finishing touch to the regulation. This valve has not in any case so far proved to be necessary, nor is it likely that in ordinary cases it will; but it is a comparatively simple method of arriving at almost absolute accuracy.

Plate 9, Fig. 6, shows the governor in use at the Swan and Edison Company's installation at Victoria Station. The action of this governor is similar in principle to the experimental governor, Fig. 1. The point in the differential lever which is moved by the solenoid is marked A, that connected with the piston-valve B, and that with the relay-cylinder and throttle-valve C.

Plate 10, Fig. 15, was prepared from readings taken between the hours of 5 P.M. and 9 P.M., during one evening at the above installation (see also Table on next page). The upper line shows the electromotive force. The middle line represents the steam pressure, and the lower line the current.

As the load comes on gradually and is taken off gradually, the steam-pressure in the boiler is usually allowed to rise during the early part of the evening, and to fall later on as the load decreases. In order to show the action of the governor under changes in steam-pressure, the pressure was allowed to vary considerably between 6.15 and 7.30 P.M., the load being fairly constant during that time. It will be seen that the electromotive force was hardly affected by these changes, the total variation being from 120 volts to 121 volts. No special precautions were taken, and the governor was not adjusted during the evening.

The delicacy of the action of this governor will be understood from the fact that the variation in speed during each revolution, of which the influence cannot be perceived on the lights or on the potential indicator, is readily noticed by watching the core of the

Time.	Current in Amperes.	E.M.F. in Volts.	Steam in Boiler.
P.M.			Lbs. per Sq. In.
5.20	230	120	85
5.40	295	120	85
6.0	400	120	100
6.15	485	120	100
6.30	485	120·5	105
6.35	485	120	100
6.44	485	120	101
6.48	485	120	97
6.53	485	121	105
7.2	485	120	100
7.6	485	120	95
7.30	500	120	100
8.0	444	120	95
8.20	420	120	90
8.40	390	120·5	90
8.45	390	120·5	85
9.0	390	120	85

governor, which perceptibly moves with each stroke of the engine. The Author, thinking at first that this must be due to vibration and not to the changes in the current through the solenoid, suspended a second core and spring similar to the one in the working governor alongside it, from a point in the same engine, but there was no motion in this second core. He then watched the behaviour of the core in the second or reserve engine, when the current generated by the first engine was passing through the solenoid from the main, the reserve engine itself standing, and found that the oscillations of the core were quite regular and as apparent as in the engine at work, and were evidently due to the change in the current during each revolution. It was thus made evident that changes in the electromotive force, much too small for the eye to detect in the lights, were enough to actuate the governor.

The Author has alluded to certain improvements in the piston-valves which greatly reduced their friction; the valve shown in Plate 9, Fig. 3, is one of them. However carefully these valves were made, if the two pistons were turned to fit throughout their length, they showed a tendency to press on one side of the cylinder in which they worked more than on the other, and the friction arising from this being considerable, a change in electromotive force was needed to move the valve. This difficulty was eventually overcome by recessing each of the two pistons of the piston-valve, thus reducing the surface upon which the pressure could act, and at the same time rendering it less likely that it would act in one direction more than another.

Plate 9, Fig. 7, shows an arrangement of governors suitable for actuating the expansion-gear of powerful engines. The travel of the solenoid is in this case also $\frac{1}{2}$ inch, but the arrangement of differential levers permits of a 6-inch stroke for the relay-piston. The grip which such a cylinder has upon the mechanism, and the great power available, renders this arrangement very suitable for expansion gears; and it is likewise suitable for automatically throwing in or out resistances, in order to obtain a constant difference of potential between two points in a circuit through which a variable current passes. The power and delicacy of this apparatus are best illustrated by the following figures:—

The mean pull of the coils on the core is 2 lbs.; this corresponds with the centrifugal force acting on the revolving balls in a speed-governor. The friction of the regulating mechanism is about $\frac{1}{8}$ oz., and the power available for actuating the expansion gear is upwards of 500 lbs. exerted through 6 inches.

The position of the regulating mechanism of the engine being adjusted by each of these governors, so as to maintain an approximately constant current through the coils of the regulating solenoid, it follows that for incandescent lighting these coils must form a shunt circuit between the positive and negative mains; but for arc lighting in series the main or a part of the main current must pass through them, the object in that case being to maintain a constant current independent of the resistance of the circuit for the time being.

The advantage of such a governor is very great, for the revolutions and the coal consumption are reduced almost in the same proportion as the number of lights, instead of its being necessary to insert resistances to take the place of the lamps thrown out and so burning the same amount of coal. A governor of this class has been successfully applied at the Ordnance Survey Office at Southampton for regulating the current used for electrotyping, and there are doubtless many other cases where it will prove useful.

The Author has so far referred to those Electric Governors which have been employed for the regulation of the speed of motors driving dynamos, to maintain either a constant electromotive force or a constant current, but these are not the only purposes for which they may be used.

Another purpose is the automatic introduction of resistances into a circuit, the current in which is generated by an engine whose speed cannot well be altered to suit the necessities of the lighting; as, for instance, where the currents in several distinct circuits of varying length and resistance are all generated by one engine.

In such cases it is obviously impossible to govern the engine to suit every circuit, but the electromotive force may be maintained constant in the engine room, and a governor of this class may be employed to insert or cut out resistances, to ensure the resistance of the mains of any particular circuit bearing always the same proportion to the resistance of the lamps in use in that circuit.

The Author will now consider a class of installation, which is probably the most difficult of all to govern, namely, one in which several independent units generate currents which are collected in a single pair of mains. This method permits of the use of a number of comparatively small units, and renders subsequent additions to the installation easy. It also very much reduces the engine-power necessary to be kept in reserve; for if, say, four engines of 100 I.HP. be used instead of one engine of 400 I.HP. a single reserve engine of 100 I.HP. is all that need be provided, whereas, for the larger machinery another engine of equal size must be available. The five smaller engines would indeed have far greater reserve power practically. In the event of a double breakdown, three-fourths of the maximum power would be still available in the smaller units, while a double breakdown would entail total darkness in the large one. There is, however, some difficulty in so regulating the speed of several units, as to ensure that each shall do its fair share of work and no more, and it would appear to be beyond the power of any centrifugal governor, unaided, to solve the problem. The Author understands that this difficulty has given Mr. Edison much trouble in New York.

Plate 9, Fig. 8, shows a regulator, which not only maintains a constant potential, but provides also that the unit which it governs shall not generate more than a predetermined current, the quantity of which can be readily varied. In this governor two solenoids and cores A and B are used. The throttle-valve, hydraulic cylinder, and piston-valve, are the same as in Plate 9, Fig. 2; but instead of the valve being connected directly to the core of a solenoid, it is suspended from a point X in a bar, the two ends of which are connected to two points, A^1 and B^1, of the respective cores. The solenoid A is wound as a shunt coil, and its duty is to control the position of the piston-valve, and consequently the electromotive force, as previously described. The solenoid B is wound with the whole or part of the main current, generated by the unit which the duplex governor controls, and it has no effect on the throttle-valve unless the current generated by that unit is greater than desired. Until then, the point B^1 is practically fixed,

the spring drawing the core up against a stop B^2. The spring is so adjusted that when the current approaches its maximum the core of the solenoid B moves down, and the throttle-valve is closed by the action of the piston-valve and hydraulic cylinder. Thus the shunt coils of the governors may all be connected to the mains, and yet the speed of each unit be so controlled by the series coils of its governor as to do its fair share of work. Shortly, the position of the point A^1 determines the potential, and that of B^1 the current; each point moves independently of the other, and each is capable of the finest adjustment, the potential by the screw A^3, and the current by the screw B^3.

If the leads of the units are all connected in or near the engine-room, the shunt coils of the governors are practically connected to the mains, but it is desirable that each solenoid should be connected to the circuit of its own unit. This is shown in Fig. 9 for two units. The "A," or shunt solenoids, are in each case connected to the terminals of the machine, while the main leads pass round the "B" solenoids before they join the mains. Assuming that at certain times unit No. 1 can do all the work required, unit No. 2 may be completely disconnected by breaking its circuit say at Y, and then shutting off steam; but it can be started again at any time, and its potential brought up to the standard by its "A" solenoid before completing the circuit again.

The same method is of course applicable to any number of units. It may often be necessary, instead of connecting the circuits of the several units in the engine-room, to run the leads from the dynamo or dynamos forming each unit direct to a lighting centre, in the manner advocated by Mr. Crompton on the score of economy in leads, when the Victoria installation was designed. In such cases it is desirable to govern each unit from its own lighting centre, so as to maintain a constant difference of potential between the mains at that point rather than in the engine-room. This may be done readily by bringing a pair of small wires to the solenoid from the lighting centre. The resistance of these wires is of no importance, as they form part of the circuit of the solenoid, in which the power absorbed is inconsiderable.

Another method, suggested by Mr. Crompton, is to wind the solenoids, with two coils acting in opposition, the one a shunt direct from the terminals of the machine, while the opposing coil is composed of a few turns carrying the main current. The effect of these series turns is inappreciable when the current is very small, and the electromotive force practically the same at

the lighting centre as at the machine; but as the current increases, the series coils, acting in opposition to the shunt, render it necessary that the latter should become more powerful in order to affect the throttle-valve, and consequently more steam is admitted to the engine, until the required rise in electromotive force takes place.

The Author has used the word "throttle-valve" by choice in describing many of these governors, but it will be understood from the description of Plate 9, Fig. 7, that they can be adapted to any ordinary form of expansive gear. If the duplex solenoids are employed in combination with the differential lever arrangements shown in Plate 9, Fig. 1 and Fig. 7, the point X in the bar between the two cores must be connected to the point "A" in the differential lever.

In this Paper the Author has only described those forms of his governor which have been made, with the exception of the duplex governor, the action of which can be foreseen. Those in which electrical relays are used have for many purposes considerable advantages, but the principle is the same in all, namely, the employment, in conjunction with a regulating electro-magnet or solenoid, of a relay of power for working the throttle-valve, the mechanism of the relay being so connected with that of the regulating solenoid, that for each position of the core there is a corresponding position for the throttle-valve, the motion of the one affecting the other as if they were rigidly connected.

The Paper is illustrated by numerous diagrams, from which Plates 9 and 10 have been engraved.

Discussion.

Mr. Willans. Mr. WILLANS said that since preparing the Paper he had had an opportunity of looking through the discussion on the one by Professor Jamieson read on November 11th, 1884, entitled "Electric Lighting for Steamships."[1] Some difference of opinion was expressed in the course of that discussion as to the best way of arranging several compound-wound dynamos when connected to the same circuit. The duplex governor which had just been described was designed in the belief that there were difficulties in that arrangement which had not yet been surmounted. The method named by Dr. Hopkinson of using the current from one machine to excite another was evidently best adapted for cases where two machines only were used, and when those two machines were of the same size. In many installations, however, this was not possible, and he thought it was desirable to show some way by which each machine might be governed quite independently, although all were connected together, and although they were of different sizes or of different types. Dr. Hopkinson gave as the reason for the exceedingly accurate compounding which had now been attained, "the fact that the field in which the armature revolved was exceedingly intense, and that the resistance of the armature was low. The error to be corrected being small, it could be reduced by the correction to an exceedingly small amount. In machines where the resistance was not so small, and a considerable amount of correction was required, it was not possible to obtain such a degree of accuracy." It was evident from this that when the resistance of the leads was added to the armature-resistance of the best dynamo made, the result of compounding might be very indifferent. On the other hand these difficulties were not felt when electrical governors were used; and it was, he thought, not disputed that it was easier to work shunt machines than it was to work compound machines together. The second point he noticed in that discussion was, that Professor Perry objected to electrical governors on the ground that the magnetic qualities of the same piece of iron were not the same at all times; but surely this difficulty must apply equally to the iron used in field magnets of a compound dynamo. His experiments had been tried in what might be called a rough way, but the same core was in some cases tried over and over again; and all he could say was that no difference of pull

[1] Minutes of Proceedings Inst. C.E., vol. lxxix., p. 24.

worth mentioning was observed. The mass of the core was of course only very small, and there was always a certain amount of vibration about it, and these facts might have something to do with the result. Professor Perry went on to say: "Given the best governor imaginable, whether electric or whether a mechanical governor, the dynamo machine being double wound, it only aimed at keeping the difference of potential constant at some one place in the system, so that a lamp at that place would be always of exactly the same brightness. But it did not follow that at a certain other place the light would always be of the same brightness. It depended on the number of lights between one place and another, and on the section of the leads. If a number of lights were switched out, there would be a different brightness in a particular lamp from its brightness before the others were switched out. Thus if there were absolutely perfect governing in the dynamo room in the Author's system, and if a room contained, say, fifty lights, fed by cables 200 yards in length from the dynamo room, and if forty-nine were switched out, the remaining lamp must have its potential increased 2·46 volts." He should like to point out that if the solenoid-circuit of one of his governors was led from the room where the lights were placed, no increase in the difference of potential would have taken place. It was quite true that an absolutely constant difference of potential could only be maintained at one point, but that point in Professor Perry's case should be the central point in the room. In the course of the same discussion Mr. Charles Friend Cooper complained that all existing governors, both centrifugal and electrical, were called into action by "a difference of that which it was desired to keep constant," and he asked "if it was not possible to make a modification of the governor in which the electro-magnet should be wound in main-circuit, in which case the strength of field would vary with the current and not with the electromotive force?" Now an electrical governor, which was to keep the difference of potential constant between two points in a circuit, might be called into action for one of two reasons. The number of lights in use might vary, or the steam pressure might vary. It was just conceivable that such a governor as that suggested by Mr. Cooper could be arranged to open the throttle-valve to a certain definite degree, so as to suit the number of lights in use at each particular time, but such a governor could not counteract variations in steam-pressure. Mr. Cooper said, referring to Fig. 18, page 61 of Mr. Jamieson's Paper: "When extra lamps were turned on, or more current flowed, the cores of the solenoids were pulled down against the spring and

Mr. Willans.

Mr. Willans. the throttle-valve was opened." Now an increase in steam-pressure caused more current to flow, and the least desirable thing in a governor would be to open the throttle-valve wider and wider as the steam pressure rose. He would prefer to put up with a known variation of, say, 2 per cent. But the point about that discussion which struck him most was this. None of the many gentlemen who joined in it referred to those cases in which a variation in speed was desirable. For his own part he considered that the most important point about electrical governors was that they ensured these necessary variations.

Mr. Maxim. Mr. HIRAM S. MAXIM said that as he had been referred to as interested in electrical governors in America, he might be permitted to give a slight outline of what he had seen in the United States. In the summer of 1877, he first took up the matter of controlling the speed of a steam-engine by the electromotive force of the current in a circuit. It seemed to him that was the correct way to control the electromotive force of a current and to maintain it constant. He could perceive that it would certainly be a great saving, because the speed of the engine would vary in proportion to the number of lights used. He had noticed the heating of a disk or a tube when rotated at a high speed between the poles of a very powerful magnet, and it occurred to him that he might employ it after the manner of the well-known American Huntoon governor, which operated upon liquids. The liquid being placed in a cylinder and a winged piston revolved in it, the tendency of the cylinder to revolve in the same direction that the wings revolved was taken advantage of for controlling the speed of the engine, as with centrifugal governors. He therefore employed the electrical governor exactly in the same way. It was connected to the cut-off gear by means of a screw. If the magnet was turned slightly ahead in the direction of the armature, it would turn the screw in a suitable direction to cut off the steam earlier in the stroke. If the electromotive force fell, a spring turned the magnet in a reverse direction, and a pawl was brought into action which turned the screw in the proper direction to let more steam on to the engine, in other words, to allow the steam to follow the piston a little further. It was, as was well known, very easy to control the speed of the Corliss engine, which only required the expenditure of very little force, and it was for this engine that Mr. Maxim designed the regulator. The first electrical governor ever put into action, was applied at Bridgeport, Connecticut, where he controlled the current by a varying resistance in a shunt around the field of a small machine that excited

the fields of the large machines which furnished the current, and it operated very well. The next was erected in 1880–81 in the Equitable Buildings, New York; but as the steam-engine could not be controlled, it was again put in to control the strength of the fields. One small machine excited several others. He made the drawings for controlling the speed of an engine of 100 HP., and had the models made. Some of the castings were out when he left the United States in 1881, since which time he did not know what had been done. He thought, however, that the Author's regulator was a better one than he had ever made. Mr. Maxim.

Mr. WILSON HARTNELL agreed so much with the Author that he had little to add to his statement. When designing the engines for driving the dynamos at the Victoria Station, Mr. Crompton directed his attention to the necessity or desirability of governing by means of the electromotive force. He had designed for the engine at the same time a centrifugal governor, by which it was possible to vary the speed at which the engine would run from one hundred and eighty revolutions to one hundred and twenty, and also alter the percentage of the variation at either of these speeds, or at any intermediate speed, which he thought was a novel thing in electric lighting. That centrifugal governor was put on, and it proved practically useless, for, from the varying resistance of the leads, and from the subsequent use of shunt dynamos, it was necessary, that the speed of the engine should vary, in order to maintain the electromotive force constant. He observed that with the electrical governor even from the heating of the leads and the dynamo the speed of the engine had been increased as much as two or three revolutions, while the electromotive force and the current continued the same. With regard to the principle on which the Author's governor worked, and the way in which the curve representing the spring crossed the curve representing the pull of the solenoid, it was exactly the same as that which he had referred to in a Paper read before the Institution of Mechanical Engineers.[1] The more rapidly the curve crossed the greater was the stability, but the greater the variation in electromotive force. The same reasoning which was there applied to show the variations of speed and "hunting," due to what was termed the "retardation due to storage," and the "retardation due to friction," applied similarly to the variations of electromotive force that would arise from friction or any circumstances that retarded the action of an electrical governor. In like manner similar reasoning to that Mr. Hartnell.

[1] Proceedings, 1882, p. 408.

Mr. Hartnell. which demonstrated that for perfect governing the centrifugal governor must be very powerful, and so arranged that for each position of the governor there must be a corresponding position of the expansion gear or regulator, applied to an electrical governor. Some of these facts had been experimentally verified by the Author. It followed therefore, that since the power of the solenoid was too feeble to act direct on the throttle-valve there must be a "relay" very prompt in its action, and connected to the solenoid core through a differential gear. All these requirements of a good mechanical governor were not only found in the electrical governor now exhibited, but were complied with in a far more delicate manner. The friction was small even in proportion to the small force available to move the piston-valve of the relay-cylinder. The relay-cylinder followed the piston-valve with a perceptible retardation. The centrifugal governor could only act slowly as the speed slowly changed, however sudden the variation of load. Any rapid change in the electrical load simultaneously affected the electrical governor. The Author had not said too much in regard to the necessity for electrical governing. He had read the Paper by Mr. Jamieson on "Electrical Lighting for Steamships,"[1] and had been astonished at the high value he had put on horse-power, and the prodigal manner in which he proposed to throw away copper, evidently for want of an electrical governor. If electric lighting was to be carried out, at any rate on a commercial scale, the engineer should take it in hand just as he took other things in hand; with a given amount of money he must produce a given result. As far as mains were concerned, it was absolutely necessary in many cases, especially where there was a small number of lights at a distance, to carry comparatively small mains, and yet keep the distant electromotive force constant. The Author had not dwelt sufficiently on that point—the absolute necessity, if electric lighting was to be economically done, of maintaining a nearly constant electromotive force many hundreds of yards away from the dynamo. The electromotive force at the dynamo was a secondary matter. The Author had not mentioned that in his first electrical governor he managed to govern the incandescent lights with a series-wound machine, made for supplying arc lamps in series, but in this case supplying about sixty incandescent lights, the result of which was very curious. As the number of lights was diminished, the speed was reduced to a certain point, at which it was nearly self-governing. Beyond that

[1] Minutes of Proceedings Inst. C.E. vol. lxxix. p. 1.

Mr. Hartnell. the speed increased until, with ten incandescent lights, the machine had to run about two thousand revolutions per minute to maintain the electromotive force in consequence of the then very weak magnetic field. That showed the sensitiveness of the electrical governor, and it proved its capabilities more than anything else. The particular forms of governors exhibited were for varying the speed of an engine to maintain a given electromotive force at a given point. The governor was also intended to regulate the speed of dynamos by acting on special arrangements when the speed of the motive power was independently controlled, such as when the dynamo was driven by a factory engine. It had already been used to regulate turbines and also resistance coils. With regard to the combinations of coils, the compound winding of the solenoids and the compounding of the solenoids, these had for the most part been designed to meet difficulties that had actually arisen in putting down installations.

Professor Perry. Professor JOHN PERRY remarked that the Author's governing arrangements appeared to be very satisfactory. They were the first really good application of the important principle that in an electric light installation, where a constant electromotive force or a constant current ought to be maintained, it was possible to use the slight inconstancies of these electric elements to regulate the admission of the steam to the engine. As the Author had stated, the principle was in itself in no way novel; but his application of it was thoroughly good and satisfactory. He should, however, be sorry to think that the designers of compound-wound machines were discouraged by the great success that had been achieved. Excellent results had been obtained by compound winding; better results, he thought, than even those which the Author had brought forward. Great stress had been laid by the Author on the fact that by means of his governing arrangement he was able to keep not merely the difference of potentials constant at the terminals of the machines, but a constant difference of potentials between any two required points of the installation. He seemed not to know that in compound winding it was possible to do the very same thing. It had been known three and a half years to Professor Ayrton and himself that compound machines could perform that function. A machine, compounded for a certain speed, run at a slightly different speed, would effect the purpose, and they could calculate the slightly different speed at which they ought to run the machine, so as to give a constant difference of potential, not at the terminals, but between any two other points. That, he thought, would be interesting to Mr. Hartnell, who had

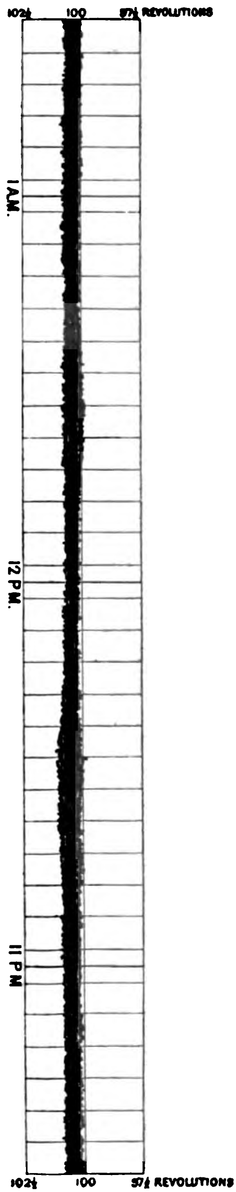
Professor Perry. spoken about the expenditure of copper in leads. Another way in which the same effect might be produced was this. Taking a shunt-machine and inserting a constant electromotive force in the main circuit fed by the machine, they could calculate that constant electromotive force, so as to get a constant difference of potentials maintained between any two points in the circuit, the machine being run at constant speed. He was prepared to give the proofs of these two propositions, but thought that although they had never been published, they must be well known to practical men. There was no function performed by the Author's electrical governor which could not be performed by the compound winding of machines or other well-known electrical arrangements, worked by a steam-engine regulated by a mechanical governor, and going at a constant speed. That fact might be taken as settled. It should also be remembered that there were some cases in which the Author's methods were inapplicable. For example, when the dynamo was one of several machines driven by a steam-engine it was rather hard lines on other machines that their speed should be altogether regulated by electrical requirements. But in many cases of important electrical installations no doubt it might be desirable to introduce that elaborate method of governing; in many other cases, however, where an installation was driven by an engine which was not driving other machines, it might not be worth while to go to the expense. After all, a steam-engine, with a very good governor, was like other engines, it could be sold and bought like them, and it could be used to drive a mill or to serve for electric lighting. The expense might be incurred of converting the engine, and of putting on electrical arrangements, to enable the admission of steam to be controlled by electrical requirements; but if it was desired to use the engine for other purposes, or even for another electric light installation, it would have to be re-converted, and then the question of expense might be of some importance. He was willing to admit that expense was of no importance in cases where the Author's method of governing had the superiority which was claimed for it. He had long been hoping that the requirements of electric lighting were rather acting on mechanical engineers, putting them on their mettle, and inducing them to endeavour to improve common mechanical governors, but that hope he was quite willing to give up if the Author's method had the superiority claimed for it. He did not, however, admit that it had that superiority. If the volts given in the Table, where it was stated that during four hours the electromotive force only varied from 120 to 120·5 volts,

were measured with the accuracy observed in a laboratory, the ground was cut from under his feet; but if they were measured by a common voltmeter, which had a considerable amount of soft iron in its composition, then he thought the Author had been misled, and that the numbers in the Table were wrong. In fact, he believed that the governor that was being tested, and the voltmeter that was testing it, had the same sort of errors in measuring rising and falling currents. He had known an instrument with a considerable amount of soft iron in its composition which was 37 per cent. in error in certain parts of its range. If another instrument had been taken of much the same construction, with a similar amount of soft iron in it, and used to test the first, the second would have recorded that the first was quite correct, both instruments really having the same fault. The principle underlying any governor of that kind was that an electro-magnet had the same magnetic field when the same current was passing through it, whether the current had risen from zero, or had come down to its present from much higher values. That, however, was not the case, and he could only explain the surprising accuracy observable in the working of the Author's governor by saying that he believed that the voltmeter was of the kind he had mentioned, and that it was wrong, for the very reason that the governor which it was testing was wrong. Professor Perry.

Mr. James Hammond observed that the result obtained by the Author's governor, namely, a practically constant electromotive force of not less than 120 or more than 121 volts, the steam-pressure varying between 85 and 105 lbs., and the current varying from 230 to 500 amperes, was a most remarkable one. The oscillations of the core with each stroke of the engine, showed that the governor was a very delicate instrument for measuring small differences in electromotive force. Might it not be made self-registering, so as to dispense with the use of a voltmeter, which, according to Professor Perry, was liable to an inaccuracy of as much as 37 per cent.? The case mentioned by Professor Perry of two voltmeters, both in error and both giving the same erroneous reading, was, he should think, very unlikely to occur, unless they were known beforehand to be erroneous to the same extent; and even with two voltmeters taken at random, there would be a strong probability of the correctness of the reading. The regulation of the flow of electricity by means of accumulators would have some advantages, one of which would be that the engine or other motor might be stopped without producing any effect on the current, the dynamo being only used to charge the accumulators, and the Mr. Hammond.

Mr. Hammond.

Fig. 1.



accumulators to maintain the current. Very variable forces, such as that of the wind, might possibly be utilized in this way; and the electrical governor could then be employed to proportion the work done to the motive power. For instance, in a windmill used for charging accumulators, the dynamo might be made to charge an extra battery when the wind was high, and when the wind fell a portion of the load could be taken off by means of the governor.

Mr. Halpin.

Mr. Druitt Halpin said it had been remarked by the Author that in cases where the speed of engines could be kept constant, electrical engineers were content if they could obtain a variation not exceeding 2 per cent. In a tandem compound condensing engine driving a large electric light installation, having cylinders 18 inches and 28 inches in diameter by 36 inches length of stroke, and making one hundred revolutions per minute, with a boiler-pressure of 100 lbs. per square inch, the engine was indicating 200 HP. from 6 p.m. until midnight, when all the lamps were turned down, after which it indicated about 100 HP. until it stopped at 6 a.m. Fig. 1 represented a diagram traced by the engine itself by the aid of the Moscrop Recorder during three hours. The engine graphically recorded its own variation, and this amounted to only 0·33 per cent. The engine had a plain slide-valve on the low-pressure cylinder, the distribution of the steam in the high-pressure cylinder being effected by Corliss gear. The distribution was controlled by a high-speed governor, supplemented by a Knowles auxiliary governor. Both the Knowles governor and the Moscrop Recorder, had been described in a Paper by Mr. Michael Longridge before the Institution of Mechanical Engineers.[1] He had

[1] Proceedings, 1884, p. 150, plates 15–19.

noticed the generous way in which the Author had spoken of what others had done, giving especial credit to Mr. MacFarlane Gray, the author of the system of relays. Mr. Halpin had a design made for him by Mr. Schönheyder in the commencement of 1882, which was practically the same thing. It was applied to one of his engines for governing the expansion-valve. Mr. Halpin.

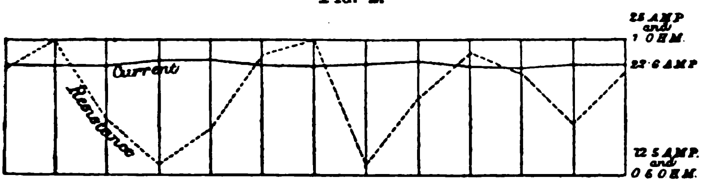
Mr. Gisbert Kapp remarked that the Author appeared to prefer shunt machines for application to his governor, but he thought it would be better to apply the governor to compound machines, because with a compound machine it was possible to get a very fair though not a perfect regulation, and with a centrifugal governor attached to an engine driving a compound machine, in addition to the Author's governor, in case of a breakdown the system would not be entirely paralysed. Professor Perry had stated that when measuring the potential of the electric-light circuit at Victoria an error would creep in on account of the voltmeter, the same error as that in the governor, in consequence of the sluggishness of the iron to take up magnetism. If, he said, there was any considerable amount of iron in the voltmeter the error might be as great as 37 per cent. The voltmeter, however, used at Victoria was one of Kapp and Crompton's potential indicators, which did not contain a considerable amount of iron, in fact the only iron present consisted of two No. 18 wires; this wire was about the thickness of a fine knitting needle. The exciting power put on to that mass of iron at 100 volts would be about 1,000 ampere-turns, whilst from 40 to 50 ampere-turns would suffice to produce saturation. With that power the iron would therefore be much more magnetized than would suffice for saturation. With 1,000 ampere-turns as an average exciting power, a variation of 10 or even 20 per cent. in the electromotive force, would not produce the slightest variation in the magnetism of the soft iron core. The indications of the instrument were therefore perfectly correct, and it was evident that the amount of magnetism in the core was practically a constant. It would be seen on a little consideration that that must be so, because the action of the governor-core was about the same as the action in the case of an arc-lamp. The arc-lamp was governed differentially, and the core followed with the utmost promptitude any change in the electromotive force. If it were, as Professor Perry supposed, an arc-lamp would never burn steadily; but they did so, the reason being that the core of an arc-lamp was fairly well saturated by the exciting power around it, and any small change of exciting power had not much chance of changing the magnetism. It should always be Mr. Kapp.

Mr. Kapp. remembered that the pull on the core was the product of the magnetism in the core with the current, and if one of the two remained constant, as it probably would, the slight variations in the current must produce a slight variation in the pull of the core. Therefore, the governor followed even such small variations of potential as 1 volt in 120.

Captain Sankey. Captain H. R. SANKEY, R.E., said that as the Author had referred to the use of one of his governors at the Ordnance Survey Office for the deposition of copper, some remarks on that subject might be acceptable to the meeting. To deposit copper for the use of the Ordnance Survey, it was necessary that the current should be exceedingly steady—practically constant—and for that purpose it was thought that one of the Author's governors would be very useful, as it had proved to be. At present a current of about 30 amperes in the mains was employed. The tanks were placed in series; and the solenoid of the governor was also in series with the tanks, so that the current of 30 amperes passed through the solenoid. In this case it was the current that ought to be regulated and not the electromotive force, so that the solenoid was wound in a slightly different way from those of the governors shown on the table; it consisted of two parts connected in multiple arc, and having together a resistance of $\frac{1}{100}$ of an ohm. The current being 30 amperes, it would be found that the amount of energy absorbed by the governor was only 9 watts. There was no difficulty whatever in fixing the governor to the engine, although it was done by the artificers at the Ordnance Survey, who were not accustomed to that kind of work. Indeed, there had been no difficulty either in the working or in the water arrangements. The filtering was effected by one of Johnson's paper filters. As to the accuracy with which the governor regulated the current, some experiments were made for the purpose of testing that point. The resistance in circuit was altered, and the current was measured for the different resistances. The instrument with which the current was measured was one of Cardew's differential galvanometers (not his voltmeter). The instrument consisted of one coil of a high resistance (1,000 ohms). Through this coil was passed a small measuring current produced by two Daniell cells, and there was a box of resistance coils in circuit, so that this current could be varied at pleasure. The current to be measured passed through the instrument by means of a large copper band, which had practically no resistance. This galvanometer might be said to be electrically what a steel-yard was mechanically, it balanced a large current by means of a small one. Matters of

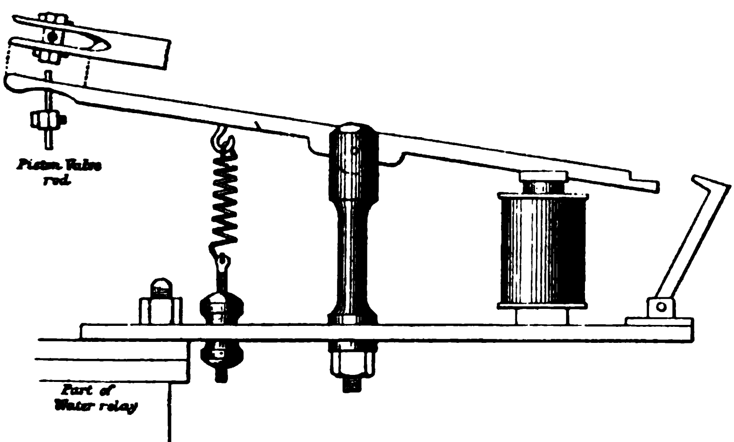
course were so adjusted that the effects of the two currents were opposed to each other, and with the instrument at the Ordnance Survey, when about 22 amperes were passing through the mains, the current could be measured to $\frac{1}{50}$ of an ampere. As the instrument depended simply on the balancing of two currents, and the resistances were not heated, the measuring current being very small, and as moreover there was no iron in the instrument, the measurements taken by it could be depended upon. Fig. 2 showed Captain Sankey.

Fig. 2.



the result of these experiments; it would be observed that the line representing the current was almost straight. The governor was one of the first made by the Author, and therefore was not as sensitive as those of a later pattern, the proportions being slightly different. Moreover, at the Ordnance Survey, the governor was

Fig. 3.



adjusted for steadiness, and, as stated by the Author, if a governor was steady, it was not quite so sensitive; therefore these results could not be expected to be so good as those shown by the Author in Fig. 8. In this governor the throttle had not got a safety

Captain Sankey. arrangement, so that if the current should cease from any cause, the full amount of steam would come into the engine. He had, therefore, put a safety arrangement on to the governor. The arrangement, Fig. 3, consisted of a small horseshoe electro-magnet placed in shunt with the main circuit; the armature was fixed to one end of a lever, and to the other end of the lever was attached a spring acting against the pull of the magnet. This end of the lever was forked, and the piston-valve rod passed through the fork; a small stop was secured to the piston-valve rod. Should the current cease, the armature would be released and the lever would come against the stop, thus actuating the equilibrium-valve of the governor to close the throttle. He had tried it repeatedly by breaking the circuit and even by throwing off the belt, in the latter case the engine going at about three hundred revolutions; it only increased to three hundred and fifty revolutions per minute, and then stopped altogether.

Mr. Richardson. Mr. JOHN RICHARDSON thought that none of the members could have heard the statements of the Author and other persons on the subject without being convinced of the great importance of electric governing in connection with electric lighting, and he had no doubt that its future development would depend in a great measure upon the electric arrangements used to control the engine. His attention had first been called to the subject in 1880, on seeing the results of the breaking of a governor belt of an engine driving an electric machine. It had occurred to him that if the governor could have been driven by an electric current instead of by a leather belt, there would have been no chance of breakage. He accordingly experimented in that direction, and succeeded in governing the engine fairly well by means of an ordinary speed-governor driven by an electric motor; but long before the termination of the experiments he arrived at the conclusion that if a solenoid could be used to work direct upon the valve, or by means of a lever, it would enable revolving mechanism to be dispensed with, and would very much simplify the apparatus. Another was constructed, and the success attending it was so great that he patented the whole apparatus. That might account for his having claimed the rotary arrangement as well as the solenoid. The machine exhibited very nearly corresponded with the first electric regulator that he made worked by a solenoid, the principal difference being that it had a double instead of a single solenoid. It acted with the same amount of current, and a far greater amount of delicacy was attained with the double than with the single solenoid. The cores of the solenoid were attached to one end of a lever, the short

end of which pressed, through the medium of a plunger, direct Mr. Richardson.
upon the stalk of a double-beat Cornish valve. The valve fitted freely into its seat, and worked almost without friction. It was, however, so arranged that the steam gave it a constant pressure upwards. This was balanced at the other end of the lever by a spring, and as the leverage was 6 to 1, the spring only needed to exert one-sixth of the pressure. There were, therefore, two forces acting in contrary directions and nearly balancing each other, and when an electric current was sent through the coils of the solenoid, the cores were drawn further in, and the valve partially closed. The parts were so balanced and adjusted that the slightest change of the current was at once felt and responded to by the steam engine with a speed and delicacy which left nothing to be desired. It would be seen that by that arrangement, although it might govern perfectly well so long as any current was passing, if the current were broken by the displacement of a lamp or anything else, it would lose all control. To prevent that an electro-magnet was fixed, forming part of the same circuit, holding a weight in constant suspension. The moment the current was broken it lost its magnetic power, and the weight fell, shutting off the steam. In the winter of 1881 the instrument was permanently applied to a steam-engine that was working a dynamo, supplying electricity in the fitting-shops of his firm. It enabled him to dispense with the constant attendance of a man at the engine and dynamo, and to effect a considerable saving in the consumption of carbons. As the apparatus was fixed by the Brush firm, all the lamps were in series. He divided them into four or five circuits, so that some might be used and others not, and not unfrequently the engine worked all night without special attention, producing just the amount of light which might be required. The engine was supplied with steam from an independent boiler. He was willing to admit that considerable ingenuity had been manifested by the Author in working out the details of his invention, but he doubted whether the use of any relays, electrical, hydraulic, or mechanical, could be nearly so direct and instantaneous in their action as the method he had described. When it was first put to work he had, like the Author, noticed some fluctuations in the position of the magnet even when the lamps seemed to be all in order. He thought that that might be due to some lack of stability in the arrangement, and he accordingly fixed some dash-pots like the dash-pots of a brush-lamp, which helped to make the instrument a little more steady, but they were found to be unnecessary. He was surprised on testing

Mr. Richardson. to find that, notwithstanding the fluctuations, the current was maintained perfectly steady, and that the solenoid was correcting the slightly varying resistances in the arcs of the lamps as they were burning. The arrangement was, moreover, free from the vice of hunting, which the Author of the Paper had been at such pains to remedy with his system of relays. Mr. Richardson would give the results of some tests made by Professor Thompson of Bristol University in the spring of 1883. The tests were directed mainly to two points. First, to find whether the current was maintained at a constant strength when different numbers of lights were switched into the circuit; and secondly, to ascertain the rapidity of action of the governor, in order to compare it with centrifugal governors.

The following Table showed the strength of current, and the speed observed at various times when different numbers of lamps were burning:—

Lamps.	Revolutions. Per min.	Amperes.	Lamps.	Revolutions. Per min.	Amperes.
17	146	10·2	11	101	10·0
"	144	10·2	"	96	10·2
"	143	10·1	"	92	10·3
"	137	10·2	"	90	10·3
"	133	10·2	"	84	10·3
"	119	10·2	"	85	10·5
16	133	9·9	5	70	10·0
"	132	10·1	"	60	10·5
"	129	10·2	0	30	10·4–10·6 } unsteady.
11	107	10·1	"	24	11·0–11·2 } unsteady.

Thus at all speeds from twenty-five up to one hundred and forty-six revolutions per minute, and with any number of lamps alight from none up to seventeen, the current was practically maintained at a constant value in the most efficient manner.

The values in this Table were from a large number of experiments, and were placed not in the order in which they were made, but in the order of the speeds. The observations were instructive in several points. The first set, made with seventeen lamps, showed how the speed, one hundred and nineteen at the moment when all seventeen lamps were fairly kindled, rose gradually (following the order of numbers to the top of the list) as the resistance of the arcs increased, to one hundred and forty-six revolutions in about fifteen minutes, the current all the while keeping within 1 per cent. of its constant value. The unsteadiness noted in the last two experiments was due to the very low speed of the dynamo, the strength of the current being distinctly varied as each section of the arma-

ture passed the magnets. The time-tests showed that when all the lamps were burning and were switched off, five at a time, the engine immediately adjusted itself to its reduced speed, the current necessarily rising momentarily, but returning to its normal value in less time than could be measured, certainly under four seconds. When the whole seventeen were turned off at once the engine pulled up in less than a single revolution, and while the momentum of the fly-wheel belt and revolving armature could not be instantaneously counteracted, yet within fourteen seconds the current was brought down, the engine just crawling round sufficiently fast to charge the magnets. When going at full speed with all the lamps lighted, the current was purposely broken. The shutting off the steam occurred instantaneously, and the engine came to a dead stop in less than one minute, the momentum of its parts being sufficient to carry it on until then. These results referred to arc lighting; and since then more than forty additional arc lights had been applied for illuminating an area covered by over 4 acres of new workshops. The engine driving them was controlled by electricity, and the lamps were turned in and out with the same freedom as gas-burners. A further installation had been made in connection with incandescent lights produced by an Edison Z A machine supplying electricity to one hundred 8-candle lamps. The apparatus was tested on the 23rd of March, after more than two years' constant work, with the following results:— Mr. Richardson.

EXPERIMENTS MADE with RICHARDSON'S ELECTRIC GOVERNOR, 23rd of March, 1885.

Number of Lamps.	Number of Volts.	Boiler Pressure.	Steam-Chest Pressure.	Revolutions.
		Lbs. per sq. inch.	Lbs. per sq. inch.	Per min.
90	53	80	50	130
80	52·5	80	47	129
70	52	80	45	128
60	53	80	43	128
50	53	80	40	128
40	53	80	36	128
30	53	80	33	126
20	53	80	30	126
7	53	80	28	125
1	53	80	26	125

From this it would be seen that with any number of lamps from one to ninety the electromotive force remained constant within ½ volt. In this case the boiler-pressure was kept constant, though a variation of 15 lbs. might be allowed without affecting the result

Mr. Richardson. more than 2 per cent. A recent application of the same invention had been made at Wellingore Hall, for Mr. R. H. C. Nevile. In this case a slight addition to the instrument permitted very great variations in steam-pressure to be made. The diagrams of the results of the Author's regulator at the Victoria Station, while only indicating a variation of 1 volt in electromotive force, also showed that the steam-pressure in the boilers was varied to suit the varying current; and from the Author's remarks it appeared that that was the rule, and it was evidently found to be necessary. So far from this being the case with the Richardson governor at Wellingore it was found that the steam-pressure might be varied nearly 50 per cent. without making any difference in the electromotive force, as might be seen from the following Tables:—

EXPERIMENTS MADE with RICHARDSON'S ELECTRIC GOVERNOR at WELLINGORE, 21st of March, 1885.

Boiler Pressure.	Number of Lamps.	Electro-motive Force.	Revolutions.	Boiler Pressure.	Number of Lamps.	Electro-motive Force.	Revolutions.
Lbs. per sq. inch.			Per min.	Lbs per sq. inch.			Per min.
31	1	90	120	45	1	90	120
35	1	90	120	50	1	90	120
40	1	90	120	55	1	90	120

These tests were made as severe as possible, the boiler-pressure being allowed to vary from 31 to 55 lbs., while only a single lamp was burning. In the next case the number of lamps was varied from ninety-one to thirty-one, while the steam-pressure varied from 32 to 35 lbs. per square inch, the lowest pressure of steam being used with the greatest number of lights, and *vice versâ*. Here the electromotive force remained constant within 1 volt:—

Boiler-Pressure.	Number of Lamps.	Electromotive Force.	Boiler-Pressure.	Number of Lamps.	Electromotive Force.
Lbs. per sq. inch.			Lbs. per sq. inch.		
32	91	92	50	61	92
35	91	92	55	51	92
40	81	92	55	41	93
45	71	92	55	31	93

Mr. Nevile. Mr. R. H. C. NEVILE observed that his engine was an ordinary portable engine that he had used for ten years, without having

its valves scraped, for sawing and pumping. When he set it to work to drive an electric lighting apparatus, it was hardly a matter of surprise that the ordinary governor failed, and that the man in attendance had to be constantly switching resistances in and out, and even then the electromotive force varied very much. When Mr. Richardson's apparatus was applied, he thought that some considerable improvement might be made in the way of compensating for the variations in steam-pressure, and also in the steam-chest pressure. He accordingly placed on the end of the core-bar a knife-edge; acting upon that knife-edge there was a lever which had another knife-edge upon it, and further back upon the lever there was a piston working in a cylinder which was connected with the boiler. As the pressure in the boiler rose, the electromotive force tended to rise unless counterbalanced, but by that means he was able to overcome any such tendency. The same idea had occurred to him with respect to the steam-chest pressure. By causing a piston working in a cylinder communicating with the steam-chest to act upon the same lever in a reverse direction, as the steam-chest pressure rose as more lights were put on, the lever had a tendency to fall; it thereby took off the pressure from under the core, permitting it to go down, and so give more steam. By adjusting the two properly, it was possible to vary the lights, and the pressures up and down within reasonable limits without any variation of importance. The apparatus had been at work about a thousand hours, during which time it had been in charge of a man who had been accustomed to drive a steam-launch. There was no difficulty with it, and it had worked very satisfactorily. He had found it working exceedingly well between such wide limits as 30 to 55 lbs. of steam-pressure per square inch and from one light up to one hundred lights. The current required by the regulator was about 1 ampere, or less than the current required by two Swan lamps; and he was of opinion that it would be easy to reduce the necessary amount of current below this. He thought that either a shunt wound machine, or a machine not entirely self-regulating, was more adapted for use with an electric regulator than one which was entirely self-regulating, for this reason: When additional lights were put on to a self-regulating machine the fly-wheel would keep up the rate of revolution for a short time, and during this time the electromotive force would rise slightly, or at least not fall, and consequently the valve would not open until the fly-wheel had begun to run slower. With a shunt-wound machine the electromotive force would at once fall slightly, causing the valve to open immediately that the lights Mr. Nevile.

Mr. Nevile. were put on. Probably where there was great resistance in the main leads it would be best to employ a machine wound for a rather less resistance. It appeared to him that this applied to all electrical governors. He hoped to dispense altogether with the levers of the steam-compensating arrangement, and to make a small apparatus which would not take up more than an inch or two of space. The piston in connection with the steam-chest might also be caused to take the place of compound winding, where it was undesirable that the governor should be connected with separate wires from the house or place where the light was used, as by properly proportioning it the electromotive force at the dynamo-terminals might be caused to rise as more lights were turned on, in any required degree, and this when only a plain shunt-machine was used.

Mr. Crompton. Mr. R. E. Crompton said he thought the previous speakers had hardly paid sufficient attention to the three great principles involved in the Paper. For the first time there had been brought forward a very delicate agent in the shape of very small changes of electromotive force or electric current, capable of actuating valve-gear powerful enough not only to work throttle-valves of steam-engines, but even the heavier kinds of expansion gear, the guide-blades of turbines, or the sluice-valves of water-wheels; in fact, any kind of mechanism no matter how much power was requisite. He had asked the Author to design for him a governor in a case where the pull required to work turbine governing-gear was upwards of a ton; in this case all the work must be done by differences of potential, causing a difference of pull on the solenoid spring to the extent of only one-fifth of an ounce.

The second great principle was that for the first time the Author had brought prominently into notice the great desirability of effecting the regulation of the large engines now being used for driving electric-lighting machinery by altering their speed. Electric lighting was the transformation of the energy of the coal into light-energy; the steam-engine itself being not the least important portion of the installation, it was necessary to consider the economy of the working of that engine. One of the greatest boons had been the introduction of the compound-engine. Taking the Woolf type, it was only possible to get economy out of it when working within certain limits of load. When very lightly loaded, most of the work was done in the high-pressure cylinder, and the low-pressure cylinder was made into a gigantic pump—acting as a drag on the other cylinder. At anything less than one-third of the normal load the compound-engine worked most uneconomically, in fact was worse than the simple engine. But

that was not the case when the Author's invention was applied. Mr. Crompton. In the case of arc-lighting, the speed was reduced in proportion to the number of lights turned off, and the engine was slowed down so as to get precisely the same cylinder charge of steam per revolution; it thus worked under equal conditions of economy, except the very slight loss due to reduced piston speed. There was also a gain in the wear and tear. Nothing tended to wear an engine so much as working at full speed when lightly loaded. There was besides a saving in lubricants, and matter of that kind.

The third great principle involved in the Paper was the control of the electromotive force or of the electric current from a distant point. If electric lighting was to be the lighting of the future, large districts would have to be illuminated from given centres, and one of the modes of accomplishing it would be to lay a network of mains throughout a district, and to feed this network at many points by laying down feeder mains, each supplied by its own engine and dynamo or system of dynamos, and each of these points could be, by the Author's method, controlled by its own separate electrical governor, each governing its own engine and dynamo. Small wires could be led back from these distant feed-points to the electric governor, situated in the engine-room, or these small wires could be dispensed with and the differential mode of winding the solenoid, described by the Author, could be used. Thus a large district could be supplied from eighteen or twenty feed-points, all of them being automatically kept at the standard electromotive force required, although the engines and dynamos supplying them might be far distant and collected under one roof. Professor Perry had stated that this could be done by the compounding of the dynamos themselves. No doubt Professor Perry had paid a great deal of attention to the subject, but he was not the only one who had done so. He would have to wind each dynamo to suit its own particular circuit, so as to maintain constant the electromotive force at the distance for which it was intended. It would be easily seen that this entailed a vast complication and enormous increase of the number of spare dynamos required; as it was not possible to make a dynamo wound for one circuit suit another circuit by simply varying the speed. If Professor Perry had looked carefully into the matter he would have discovered a great difficulty in doing this, for the alteration in speed would produce a result exactly the reverse of that required. If a dynamo was required to supply a longer circuit than that for which it was originally wound; instead of running it quicker to get the higher electromotive force required, it would be

Mr. Crompton. necessary to make it run slower, in order to make it regulate properly. He was surprised at the statement of Professor Perry with regard to soft iron, which was directly in the teeth of authorities such as Professor Hughes and others who had repeatedly shown that when soft iron was subjected to mechanical disturbance, it rapidly lost its residual magnetism. As a matter of fact, the solenoid cores of these electric governors were in a perpetual state of vibratory dance, and therefore in a very favourable condition for shaking out the residual magnetism, and, of course, the instrument by which the electromotive force was measured at Victoria, and referred to by Professor Perry, was in the same condition. In any engine-room it would be in a considerable state of vibration. The readings were taken by rapping the instrument with the knuckles, and in some cases by actually switching off the current and reversing it. He had himself checked these readings by other instruments, and it was found that the readings corresponded, and there was no trace of the action mentioned by Professor Perry. It might, therefore, he thought, be taken as pretty fairly established that the instrument used was as accurate as instruments ordinarily were. It was not easy to make instruments measure within 0·5 per cent.; but by knowing the instrument, and by checking it by taking the mean of several readings from several instruments, it was possible to accomplish that object. Mr. Richardson's governor was a very ingenious and beautiful piece of mechanism; but as it acted direct on the throttle-valve itself, without the aid of any relay, he could not understand how it was possible that it should have sufficient power to get over the friction of a stuffing-box, and other frictions incidental to such a system, or that it could at all compare with the delicacy of the solenoid used only for working the hydraulic relay of power shown by the Author. So long as the Author's governor had a stuffing-box as shown in Plate 9, Fig. 1, even for the low water-pressure of the hydraulic relay it was not as delicate within 2 or 3 per cent. as the instrument shown in Plate 9, Fig. 2, where there was no stuffing-box, the rod passing out open to the air. He also thought that, in order to get Mr. Richardson's instrument to work at all, a comparatively large amount of electrical energy would have to be wasted, as compared with that wasted in the Author's exhibited, which, to the best of his belief only used half the energy taken by a Swan lamp, namely 35 watts. One important use of the dynamo machine was the charging of accumulators. For that purpose a constant current was required, and a large number of batteries

uncharged in series, an arrangement which led to great economy in the cost of conductors, as the use of the electric governor would allow the batteries to be turned off set by set as they became charged. He was now carrying out an installation on a very large scale for the Imperial Continental Gas Company, of Vienna, using governors of the Willans type. In this case the engines would be governed so as to vary these speeds from one hundred revolutions when quarter loaded up to four hundred revolutions when fully loaded. Mr. Crompton.

Mr. JAMES SWINBURNE referred to the great importance of the subject with regard to the life of glow-lamps. No data existed on the subject, but it seemed probable that there was a certain temperature under which lamps lasted indefinitely, and above which they would break comparatively soon; but at present that temperature was not known, nor the corresponding efficiency. As to the inaccuracy due to the core, he had, after working on governors a little over a year, tried a core to see what the inaccuracy was. He had a freely-suspended core, and on altering the electromotive force on the solenoid there was an error of about 3 per cent. His solenoid and core were not so well designed as those of the Author, so that he thought the error must be under 3 per cent., probably under 1 per cent. It seemed to depend on the degree of saturation of the iron. He had also made instruments, and with one of them, if the current was increased gradually, say till it reached 2, and then increased very much, and reduced again till another instrument would show the same current as the original one, it would read 3½. Taken one way, it was 75 per cent. wrong, and he of course rejected it. He had also rejected the solenoid on account of inaccuracy. The next point that he had noticed was that the governor seemed to act on the engine though it might be arranged to govern the dynamo, and the two systems had not been compared. In governing an engine, the great fault was sluggishness, and the Author had found difficulty in that matter. Mr. Swinburne had worked at the problem of governing by an exciter circuit, and there the action was so prompt that a very small dash-pot sufficed to stop the hunting. In governing an exciter which acted on another machine, a bigger dash-pot was needed. He did not see how the governor could be applied to all engines, if special draughtsmen had to be employed to design different methods of governing. The particular examples shown seemed to refer to throttling the steam, which was not a good way of governing an engine as a rule. Of course, as the Author had pointed out, the instrument could be put on to Mr. Swinburne.

Mr. Swinburne. anything, up to the heaviest expansion-gear, but then it must be designed for each engine. Another point was that an engine was needed for each dynamo, whereas there was an extensive field for putting dynamos on mill-engines and factory-engines, which varied constantly with the work; and if the field could be governed, the dynamo could be put on the engine, the only trouble being the liability of sparks at the brushes and a slight want of economy. Mr. Willans appeared to regard the shunt-machine as the most economical, but it was really the least so. Professor Perry had said that the best way was to compound dynamos and to run with isochronous governors. Generally, when a mechanical engineer invented an isochronous governor, he made it nearly isochronous in theory, and hung on a large expansion-valve or a heavy stiff throttle-valve, and the friction took away, so to speak, all the isochronism. He did not think that, with an engine going at a uniform speed, by any compounding could a dynamo be made to run accurately on account of varying belt slip.

Mr. Girdwood. Mr. W. W. Girdwood had taken out a patent for accurate governing in 1880. In this apparatus he used a relay of steam power to close the throttle, and the small slide-valve had but $\frac{1}{32}$ inch travel, and was actuated by very delicate mechanism, the opposing springs being very small. The action being so minute, he thought he had eradicated the defects of others and of larger governors, because with this apparatus he could govern to within a few degrees of the crank's path; but perfect synchronism was not obtained, as the inertia of the delicate springs was sufficient to spoil the effect. He found that to ascertain minute increments of speed, the brake must be very sensitive. Now, as this governor was in its mechanical details similar to the ingenious device of Mr. Jamieson for governing electric light; and as the electro-magnets would act as a sensitive variable brake, opposing the rotation of the disk, then with a relay of power actuated by a slide of small travel, Mr. Jamieson's apparatus would approach very near to synchronism. In order to get a sensitive variable break, and to annihilate inertia, Mr. Girdwood subsequently used a light hollow drum containing a liquid weighing much more than the drum and its shaft: and in quantity one-third of the cubical capacity of the drum. With this apparatus he could govern marine engines to perfection; but there was the possibility, although perhaps very remote, of the machine swinging, of its having a period due to the oscillation of the ship. He next came to the conclusion that electricity was the only agent capable of dealing with the difficulties of marine engine governing, and in

1882 he obtained a patent for an electric marine governor, which was simply an electrically-operated relay of power, and which he found to be the very same kind of contrivance brought out by the Author at a later date. He did not wish to detract from the merits of the Author's patent; but what he objected to was, that in his chronology of the subject, the Author had omitted to state that Mr. Girdwood had done the same thing for marine governing that he himself did for electric lighting. Mr. Girdwood.

Dr. J. A. Fleming said that the value of a governor, able to control the supply from a distant point, was best illustrated by the state of things in the New York Central Illuminating Station. There were twenty feeders going beyond the point at which eight dynamos working the station were coupled together. Those feeders branched out to twenty different points in the network, and supplied a current necessary to keep alive twelve thousand lamps. The great difficulty was in maintaining the potential constant at those different points. The consumption in the station varied from point to point; it was greatest on one side in the daytime, and on another side in the night. The result was that there was a continuous rise and fall, which seriously affected the average life of the lamps. In fact they did not possess more than half the life which they ought to have, if the potential were properly governed. The only method of adjustment adopted was that of knocking out of use certain feeders. When the consumption at one point was falling off, certain feeders directed to that neighbourhood were knocked out, in order to prevent the potential rising there. That, however, was a very crude method. In the tube which conveyed the feeders an insulated wire was run out attached to the point where the feeders entered the net-work, so that the potential at those distant points could be measured. If instead of working the plant as now, the dynamo power attaching it to the different feeders was separated, and one of the Author's governors put on to the regulating wire, a simple and beautiful mode of maintaining the potential constant at the twenty points would be established. Allusion had been made to the importance of keeping the potential constant for the sake of the life of the lamps. His attention had been recently directed to the connection existing between the life of lamps and the electromotive force. For the Edison lamps there was a tolerably approximate law, the life of the lamp being inversely as the twenty-fifth of the electromotive force; so that if the electromotive force varied, it was easy to see that a slight rise made a serious difference in the life of the lamps, Dr. Fleming.

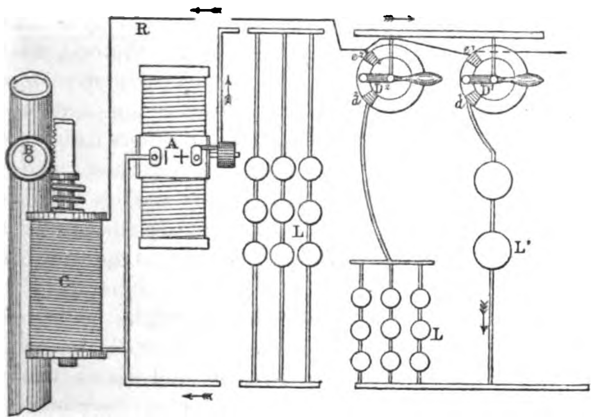
Dr. Fleming. and that by the employment of means for keeping perfectly constant the electromotive force, the average life of the lamps might be greatly prolonged. The Author's governor, therefore, was likely to be a considerable improvement in large installations, not only in maintaining the uniformity of light, which was so essential in order that incandescent lighting might possess the greatest beauty, but also in keeping down the cost of the installation, of which lamps formed a not inconsiderable proportion.

Mr. Shoolbred. Mr. J. N. SHOOLBRED thought that great credit was due to the Author for his ingenuity in working out his apparently useful means of regulating dynamo machines; so far, however, the members were dependent for the account of its working in a great measure upon the statements of the Author as to the results at the Victoria Station. The variation of electromotive force appeared to be very small indeed for so long a period as four hours. On several occasions while passing through Victoria Station he had observed a far greater variation of electromotive force than was shown in the diagram. He mentioned this matter also on account of the difficulty which he and many others had experienced in the accurate reading of volt-meters. Even those made by the same makers varied, and those of different makers could scarcely ever be made to agree. It would be a great advantage to have ready access, if possible, to some practical standard, consisting not merely of a single voltaic cell, but registering to some 200 volts or more, by which volt-meters might be tested, so as to settle disputes, which sometimes arose with makers, as to whether the lamps had been tried over and above their proper electromotive force. Besides the method of regulation of the electromotive force and of the current by an electric governor, such as described by the Author, there was another mode of effecting the same object, namely, by the addition of an accumulator to the dynamo, and which acted as a regulator of the pulsatory current given off by that machine. It would be interesting to know whether the method of the Author afforded an easier and less costly mode of accomplishing the object, though there would always remain the additional safety which accumulators afforded in every installation by the property of storage possessed by the secondary battery. The considerable improvements, which had been made in the construction of those secondary batteries, were having the effect, he was glad to observe, of causing those most useful adjuncts to each installation to be gradually creeping into use. There, however, remained their almost prohibitive price, to which the makers of them still adhered. An

effective electric governor would always prove a valuable adjunct to an installation, if only on account of the saving in fuel which it promised to accomplish. Mr. Shoolbred.

Mr. KILLINGWORTH W. HEDGES said the Author appeared to prefer the solenoid to the electro-magnet, but Mr. Hedges considered the latter had some distinct advantages. It was cheaper, less liable to get out of order, and on board ship he thought it would be better than the solenoid. The ordinary electro-magnet was not very sensitive, but he thought it might be improved. A short time ago he had an opportunity of watching the action of the electro-magnet used in the automatic regulator of the Thomson-Houston dynamo; the pole of this magnet was made approximately Mr. Hedges.

FIG. 4.

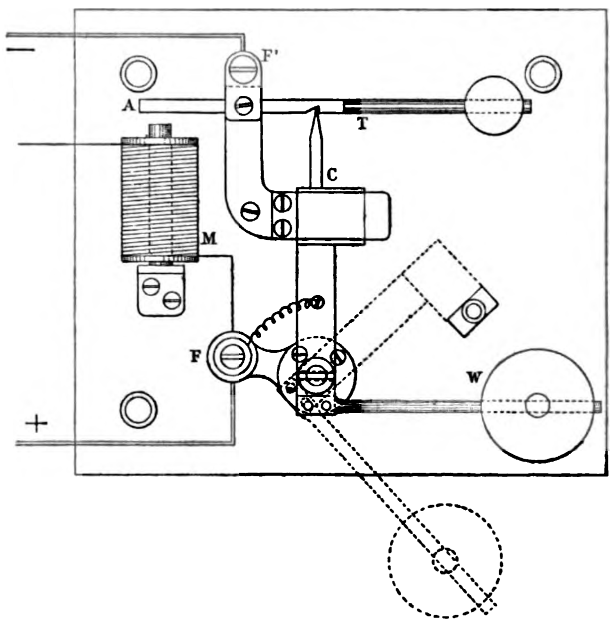


HEDGES' SYSTEM OF CONTROLLING SPEED FROM A DISTANCE.

of parabolic form, and loosely entered a conical hole in the armature; this plan had the effect of making the pull the same throughout the stroke. He had been informed by Professor Thomson that a magnet of that kind would give the same steady pull as a solenoid of much larger size. The method was about to be shown at the Inventions Exhibition, so that the members would be able to see how a magnet could be made to regulate in a very delicate manner. The Author seemed to think that electrical governors were a necessity for electric lighting. In the case of a large installation like that at Victoria Station they were a necessity, but for small work, on the ground of expense, he hardly thought they were to be recommended, because there were so many installations working perfectly without them. When it

Mr. Hedges. was required to govern at a distance, and to allow for the increased resistance of wires if the whole current was passing through, it was necessary to increase the speed of the dynamo. In order to do this he had contrived an arrangement which was used for governing a turbine working at some distance from the lamps. The plan adopted was to separate those lamps which were turned on last, and let them work through an independent return-wire; or, as shown by Fig. 4, when desirous of regulating to send a small amount of current through a

Fig. 5.



Hedges' Automatic Cut-out.
Scale ¼.

similar return-wire, which at the dynamo-end included a solenoid, this, when actuated by the current moved a balanced valve, so letting on more water to the turbine. Fig. 4 showed how this arrangement might be applied to control the speed of the motor from a distance. L represented those lamps which were usually employed, and L′ L″ groups of lamps some distance away, which might be occasionally required. In order to increase the speed of the dynamo A, when L′ and L″ were turned on, the switches D^1 and D^2 were placed at d^1 and d^2, so as to divert the

current through the return-wire R, which included in its circuit the solenoid C actuating the valve B. He should like to ask the Author how the electrical governor worked when there was a short circuit? He had stated that when the potential dropped to a certain extent, the spring held the core up and shut off the steam; but if the engine was working several dynamos, and a short circuit took place on one pair of leads, it appeared that all the dynamos would be stopped. He hardly thought that any arrangement could be depended on to the exclusion of a cut-out of some kind. It was not always necessary to use a fusible cut-out. Automatic cut-outs had been designed, and he had himself recently brought out one. It consisted simply of a lever, which was weighted so that directly a small catch was released, it fell by gravity and severed the circuit. It was actuated by a little magnet which was in a shunt circuit. The great advantage of this plan over others was that a small magnet, wound with fine wire, could be made to control any sized installation. Fig. 5 represented this cut-out. The main current entered at F, passed through C, and left at F^1. A small portion was diverted at F through the high resistance magnet M, which was connected to some part of the line which would give such a difference of potential as to allow $\frac{1}{8}$ ampere to flow through its coils. Directly the current in the main circuit exceeded a certain amount, the excess which passed through the shunt M attracted the armature A, released the tripping lever T, and thus allowed the contact piece C to be quickly withdrawn, and opened the main circuit, which could not be re-established until the current flowing through M was reduced. The members, he thought, were obliged to the Author for the clear and unreserved way in which he had placed all the details of his apparatus before them. Mr. Hedges.

Mr. Worby Beaumont desired to emphasize the remark made by Mr. Crompton with respect to the regulators, as distinct from governors in the ordinary sense of the term. A short time ago in the course of a discussion on a Paper read at the Institution, a remark was made that it was impossible to get a mechanical governor that should govern engines within a very large range. At that time Mr. Beaumont made some observations on the subject which had given rise to some misconception. In the present Paper it was plainly stated that mechanical governors might be had to govern engines within even 2 per cent. and perhaps less, thus fully confirming the remarks that he had made, which were not with respect to regulating engines, but as to governing them in the ordinary sense of the word. As the Author had pointed out, his instruments acted as regulators to change the Mr. Beaumont

Mr. Beaumont. speed of the engines constantly in accordance with the work to be done, instead of keeping the engines at a regular speed, a very different purpose, and one for which the Author's regulator had answered well in practice.

Mr. Preece. Mr. W. H. Preece thought one point in the discussion had not received due justice. It was indeed the prime question, whether a real necessity existed for electrical governors. He was bound to confess that he looked with a great deal of suspicion upon the employment of any automatic gear that tended to shift the responsibility of the accurate working of machinery from the man in charge to a delicate apparatus of any sort. To introduce an apparatus such as had been described, which with the pull of half an ounce would exert a pressure of a ton, was placing under the influence of machinery a force or power that should rather exist in the hands of those who were in charge of the work. Nor had sufficient support been given to the mechanical governor. Of all the various electric-lighting installations that he had examined he had found that mechanical governors acted with extreme promptitude and with great accuracy, and if properly controlled (not as Dr. Fleming and he had seen in the United States by a boy, but by competent engineers) he thought they would meet all the requirements of electric-light installations. There was one great advantage that an electrical governor had over a mechanical governor. The mechanical governor only operated by the variation of the very thing it was required to control, while the electrical governor acted directly by the application or operation of the load itself. If it were possible to utilize the variation of the load to govern engines, he thought a great work would be performed, but a difficult and awkward element introduced, the element of time, and excellent as the apparatus of the Author was, he was not sure that the element of time being introduced did not detract from it in respect to its superiority over mechanical governors. During a recent visit to the United States he had inspected a great number of central stations. There was a large central station at Montreal, worked by Messrs. Thomson and Houston, and there was also a central station at Philadelphia, where 1,200 HP. was employed to light up the streets of that city, extending over a distance of from 11 to 14 miles. There was also the central station referred to by Dr. Fleming, where 12,600 lamps were employed daily; and there were besides other very large stations operating other systems; but in no instance was there the application of any automatic contrivance, electrical or otherwise, to control the variations of the steam with the changes of the load. If such a practical, ingenious race as the Americans

Mr. Preece. had not found it necessary to apply such contrivances, he thought there must be some objection or difficulty in the way of carrying them out. No doubt there was a necessity for some mode of controlling and governing due to irregularity of motion. A gas-engine, for example, was an annoying instrument, especially when it was employed in producing electric light; but it was possible to regulate the current generated by a gas-engine with absolute perfection, not by electric governors, but by means of accumulators. If an accumulator were placed as a shunt similar to the lamps, then if the number of cells were such as to give the electromotive force required to raise a lamp to its proper incandescence, the current in the circuit would be absolutely and perfectly steady. He had his house fitted up with a gas-engine with a dynamo and with incandescent lamps, and he originally used an accumulator as a governor with perfect success. But he found it was more than that, for while it acted as a governor during the time the engine was working, when the engine ceased a store of electricity remained that gave sufficient light to last the whole night. That gradually attracted his attention, and from being an opponent of accumulators he had become a supporter. He now had accumulators that enabled him to light his house for a whole week with the employment of an engine for one day. At the Society of Arts also there was a gas-engine, which had flickered and caused a great deal of inconvenience, and there, too, accumulators had been applied with success. It was simply a question of pounds, shillings, and pence. He thought that accumulators were more expensive than the Author's governor, but they had the advantage of giving a store of electricity when the engine had ceased to work.

Mr. Willans. Mr. WILLANS, in reply, said that he could not see the force of the objection raised by Mr. Preece to electrical governors, namely, that they were not used by the Americans. The other objections might be divided into two classes; those which applied to electrical governors generally, and those which applied to the Author's in particular. Professor Perry's objections were the most sweeping. One was that electrical governors could not be applied to regulate an engine, the speed of which was determined beforehand by other considerations. In the Paper, he had pointed out that in some cases electrical regulators might be used to vary automatically the permanent resistance of the circuit, so as to ensure that it bore always the same relation to the resistance of the lights in use, and a number of governors had already been constructed for this class of work. An electrical regulator might also, when each machine supplied one circuit, be applied, as sug-

Mr. Willans. gested in Andrew's patent, and carried out by Mr. Maxim, to vary the currents passing through the field-magnet coils, and the Brush automatic regulator did the same thing for arc-lighting; although it seemed to the Author that it was not desirable to effect the regulation in this way if the speed of the engine could be altered. When in incandescent lighting a compound-machine alone could meet the difficulty, it should certainly be used; but he ventured to think that the cases in which the governing of existing engines, used for other purposes, was not sufficiently exact to enable compound-machines to show the accuracy which was claimed for them, were at least as numerous as the cases where those machines unaided could solve the problem. Professor Perry's most serious objection, however, was that electrical governors were utterly unreliable, because there was soft iron in their composition, and because, therefore, with rising and falling currents through the solenoid, the field was not always the same for the same current. He had alluded to this matter, and to the views which Professor Perry had expressed in the course of the discussion on Professor Jamieson's Paper, before Professor Perry had spoken, but he had not given any further explanation. The Author would, therefore, again point out that if the thin core of the solenoid was so utterly unreliable, the comparatively heavy field magnets of a dynamo must be far more so, for the variations of current in the case of the field magnets of a compound machine must be enormously in excess of those in the solenoid coils of the governor.

He contended, however, that there was an excellent practical reason why the difficulty should not exist at all, for, as Professor Hughes had shown, the slightest vibration was enough to free the iron from residual magnetism, and these governors being used in all cases near machinery, it was impossible that they should be free from such slight vibration. There was also another reason why such a difficulty, if it did exist out of a laboratory, could not be a practical one. Professor Perry spoke of the governor as if it were a volt-meter, and was habitually used to measure widely varying electromotive forces; but this was very far from being the case. When the engine was started the electromotive force would rise from zero until it reached its normal value of, say 120 volts, and if the governor acted properly it would never rise during the evening more than 1 volt or 2 volts; in the case of the Victoria governor the highest rise indicated was 1 volt. To what extent in such a case could the magnetic field be a variable one? If the electromotive force varied from 150 volts to 90 volts he could understand the argument, but it seemed to him that by Pro-

fessor Perry's own showing the error to be feared in such a case could only be a small percentage of less than 1 per cent. For the sake of argument he would admit that the variation shown on the diagram might be 37 per cent. in error, as was the case with the volt-meter Professor Perry tested; this would increase the variation to about 1½ volt, and he thought even that variation would compare very favourably with the variations usually found in installations where compound machines and centrifugal governors were used. The governors had, however, been thoroughly tested by methods to which these objections did not apply. The experimental governor shown had been tested repeatedly by means of a Siemens dynamometer. The late Mr. Robert Sabine, who took a great interest in the governor in its infancy, had tested it also, using a mirror galvanometer, and even then when the arrangement of the details was comparatively imperfect the variation in electromotive force was but 3 per cent. with 85 per cent. range of load, and a series dynamo. Mr. Willans.

The governor had been tested also by Captain Sankey, who had used a Cardew's galvanometer, and by himself and others with Messrs. Crompton and Kapp's instrument, and last but not least with Messrs. Ayrton and Perry's. The readings at Victoria Station were taken with Messrs. Crompton and Kapp's volt-meter; but the variations shown by all were substantially the same. The large governor exhibited had been tested experimentally with a Cardew's volt-meter, and it had been found that a variation of much less than 1 volt in 120 volts called it into action. There were of course cases in which extremely sudden changes of load necessitated very great stability in the governor, but in incandescent lighting these cases were the exception, and he was not exaggerating when he said that the ordinary variation was less than 2 per cent. This variation ought not to be confounded with the variation shown by the characteristic curve of a compound machine. As that variation was generally given, an absolutely constant speed was assumed, but to obtain that constant speed by mechanical governors, far more elaborate arrangements than the Author's electrical ones were necessary. Professor Perry said that he had been hoping that mechanical engineers were being put on their mettle by these electrical difficulties, and he thought that his hopes had been realized. Conditions such as these—"revolutions 450 to 500," "the governor must control the speed of the engine within 1 per cent"—were very easy ones to lay down, but they were much simpler than the governors which they necessitated; and when to these conditions it was added that "the speed of the

Mr. Willans. engine is not to alter when 90 per cent. of the load is suddenly thrown off," he thought that engineers might fairly be said to be "on their mettle." Professor Perry stated, however, that "there was no function performed by the Author's electrical governor, which could not be performed by the compound winding of machines or other well-known electrical arrangements, worked by a steam-engine regulated by a mechanical governor, and going at a constant speed." This was not his experience, for one of the principal functions which his electrical governors had had to perform was that of adjusting the inaccuracies in the calculated speed of machines, and until machines could calculate their own speeds and work at them, he thought that this function would still require to be performed for them. It was easy enough to find fault with the mechanical governors when lamps were spoilt; but it ought to be remembered that in order to make an accurate speed-governor, accurate data must be supplied, and it was not very easy to make a mechanical governor correct through a large range of load, and at the same time stable and capable of being easily adjusted to any speed electricians might require. In the course of last year a case came under his notice, in which machines designed for four hundred and fifty revolutions gave the necessary electromotive force at four hundred revolutions. In another case, in which the revolutions were expected to be nearly five hundred, they actually were three hundred and eighty; in a third, engines designed to run at six hundred revolutions were driven for some time at seven hundred and twenty; in a fourth case, engines designed to run at one hundred and eighty revolutions were subsequently driven at little more than half that speed. When he said that such changes as these, provided always that they were within the capacity of the motor, could be arranged without difficulty in designing electrical regulators, he felt sure that it would be seen that some of the functions of these regulators were peculiar to them. To put the matter shortly, a compound machine once made was well adapted for one piece of work, but an electrical regulator would adapt either it or a shunt-machine to any piece of work within wide limits. If, for instance, it was found necessary to use lamps of different electromotive force, the compound machine was at fault, but a few turns of the adjusting screw of the electrical governor adapted it to its new work, and most important of all, the adjustment could be made by anybody without the necessity for elaborate calculations or experiments.

The picture of the errors to be expected in volt-meters, and of the uncertainty attending electrical measurements was a dismal

one, but surely, if it was not exaggerated, it could only be taken as an additional reason for employing governing apparatus which could be readily adjusted. His answer, therefore, would be this:— Mr. Willans.

I. That whatever the extent of the error introduced by the soft iron core, it was small compared with the corresponding error in the compound machine.

II. That in cases where the action which Professor Perry dreaded took place, or might be supposed to take place, the percentage of error introduced was infinitesimal.

III. That in the great majority of cases the soft iron could not for well-known practical reasons do any harm.

He had not intended to express the opinion that compound machines ought in all cases to be superseded by electrical regulators: each method had its proper sphere, and in some cases, undoubtedly the best result of all could be obtained by the use of the two together. He contended, however, that it was straining the argument for compound machines to seriously propose the winding of a special machine for each circuit. He was willing to admit that there were many cases where the exact nature of the work could be foreseen from the commencement, but there were also many where it was not so easy to foresee it, and he was sure that there would be very many cases where for economical reasons the permanent resistances of the various circuits would be so large, and so widely different, that compound machines could only be used by sacrificing altogether the interchangeability of the various units, in which case there could be no doubt as to which method would carry the day.

It had been shown by Mr. Halpin with what accuracy mechanical governors of suitable construction could be made to govern an engine, but he would like to point out that at Victoria Station an engine governed with such accuracy would introduce an error in electromotive force of about 10 per cent., that being roughly the variation in speed from time to time if the difference of potential remained constant.

Allusion had been made to a relay designed by Mr. Schönheyder, very similar to the Author's, as shown by Plate 9, Fig. 2; there was, however, an important difference between the two, for Mr. Schönheyder's was proposed for use in connection with a centrifugal governor.

The remarks by Mr. W. H. Preece appeared to imply that it was a question of electrical governors or accumulators, but since the Paper was written several governors had been put in hand for use on engines and dynamos charging accumulators, the object

Mr. Willans. being to maintain a constant current, the speed of the engines varying according to the extent to which the accumulators were charged, and the electromotive force consequently required.

In reply to Mr. Hedges' question, he did not expect that electrical governors would supersede automatic cut-outs; he only intended to say that in the case of a large short circuit the governor might be arranged to stop the engine.

Although Mr. Richardson agreed that electrical governors were desirable, he objected to the principle of relays, and claimed great advantages for his governors, in that they were more direct and instantaneous in their action. Undoubtedly they were more direct, but judging from the figures given by him, they did not appear to be more instantaneous, but the contrary if anything. The question of relays was, however, a far larger one than this; he had found by experience that, for the variation in currents to be small enough not to be felt in the lighting, it was necessary, even with a piston-valve requiring only $\frac{1}{8}$ oz. to move it, to use a solenoid having a maximum pull of 1 lb., or about eighty times the pull required to overcome the friction. If the friction of this piston-valve was compared with that of any stuffing-box, it would be seen that a very large and powerful solenoid would be necessary to overcome the latter, and when the chances of careless packing of the gland were considered a still larger reserve of power must be allowed. It had been the Author's special care to avoid stuffing-boxes and their accompanying uncertainties. Mr. Richardson had only so far apparently applied his governors to small throttle-valves, and even with one of these it had been necessary at Wellingore to add compensating mechanism to counteract the variations in steam-pressure. It was unfortunate that this compensating mechanism was not more fully described, but as it consisted of two pistons and lever-connections to the solenoid core, it involved at least as much complication as the use of a relay. Remarks had been made by Mr. Richardson upon the variations in boiler-pressure shown on the diagram, Fig. 15, but this was surely the natural thing to expect in any installation where the time when the maximum work came on was known beforehand. The stoker allowed the steam-pressure to rise gradually during the early part of the evening, and reduced it towards the close of the run. The relay governor was as sensitive to changes in steam-pressure as it was to changes in load, and the pressure on the throttle-valve spindle, the friction of the glands, or any little disturbing element of that kind was no drawback, and introduced no fresh complication. Where the governor had to work expansion

gear, or regulate a turbine, or do any heavy work whatever, the size of the solenoid became a much more serious matter, and he thought Mr. Richardson could hardly contemplate its direct connection to the regulating mechanism in such cases. He was glad, however, to find that Mr. Richardson's experience as to the advantages of electrical regulation agreed with his own, and that they were only at variance as to the best method of carrying it out. Mr. Willans.

Correspondence.

Mr. JOHN HAYES, whilst admitting the great value of a simple, independent and effective means in electric lighting installations, of electrically controlling the quantity and force of the electric current by electrical governors, according to the demand, which was subject to constant change, held that electric-light engineers and manufacturers who designed and supplied the motors should take care that the motors and motive power were also self-controlling, and that too quite independent of the electrical arrangements. The engine should be fitted with some simple and effective governor, and the boiler itself, with its equipment, should be also designed and arranged in such a manner that a steady fixed boiler-pressure could under ordinary circumstances be relied upon, as in his opinion the variation in speed and irregularity of motors generally, with the accompanying flickering and unsteadiness of the electric light, were owing as much to the variations of pressure of steam at the boiler, as to any alterations in the resistance or load upon the engine. The manner of how best to overcome these difficulties, beginning with the boiler, had been thoroughly put into practice by Sir David Salomons, Bart., Assoc. Inst. C.E., at Broomhill, near Tunbridge Wells; which he had illuminated by means of the electric light; the plant and installation having all been planned and put down under his instructions; in addition to which he had stocked and fitted up a complete workshop, many of the machines in which were driven direct by the electric current. In this installation Sir David Salomons had adopted automatic appliances wherever possible; beginning at the boilers he had fitted these with Fromentin's automatic boiler-feeders, an apparatus by means of which a constant water-level was automatically maintained inside the boiler, the feeding being gradual and corresponding exactly with the rate of evaporation, independent of the attendants. The automatic feeder, by means of a counter placed in Mr. Hayes.

Mr. Hayes. the engine-room permanently recorded the quantity of water passing into the boiler, and thus afforded valuable data and comparisons as to power developed and economy in working; thus all the irregularities common to boilers fed with donkey pumps and injectors were got rid of. The same principle had been applied throughout the entire installation; the engines had been fitted with sensitive centrifugal governors, and automatic appliances and expedients were applied to the electric lighting system wherever practicable; the result being great regularity and steadiness in the light, accompanied by a degree of economy in working not often found in practice.

Dr. Hopkinson. Dr. J. HOPKINSON remarked that the Author stated that the pure shunt machine was "most economical theoretically." If there were no insulating material needed between the successive coils on the magnets, shunt, series, and compound machines would theoretically be exactly equally economical. But the use of insulating material made the shunt machine theoretically a trifle less economical than a series machine, for less copper could be put into a given space.

With regard to the method alluded to of controlling potential at a distance without the use of supplementary wires by the use of opposed coils, one coil carrying the shunt current, the other the main current, he would direct attention to the fact that this method had been fully explained in a patent of his own, No. 3576 of 1882. No doubt Mr. Crompton had arrived independently at the same solution of the problem. In his patent Dr. Hopkinson also pointed out how to adapt this method to the three-wire system of conductors. The Author was probably right that in a system of electric lighting supplied by several dynamo machines the use of compound dynamos would present some difficulties which were not met with in the system of governing which he had developed. It was, however, to be noted that this system made the engine the unit of supply instead of the dynamo, and it was doubtful if this would generally prove most convenient. His own impression was that it would be found best to make the engine-units larger than the dynamo-units, and to govern the potential of the dynamo separately, either by compounding or by introducing resistance into the magnet circuit of the dynamo by hand or automatically. The latter plan possessed the advantage that it controlled the irregularities of the engine, which compounding did not.

Mr. Mordey. Mr. W. M. MORDEY remarked that the Paper dealt with the regulation of electromotive force or current by the alteration of the speed of the engine. In many cases, however, it was required to

run dynamos from the line shafting in factories, or in other places where the engine was doing other work, and was, perhaps, running irregularly. In such cases the regulation had to be effected at the dynamo itself. Perhaps equally important with the problem which the Author had so successfully attacked, of the maintenance of constant electrical supply by variation of speed, was that of getting the required effects in spite of variations of speed. This was often necessary in arc-lighting. He was surprised to find that Mr. Richardson had kept the full load of sixteen arc-lamps burning when only one or two were required. This was quite unnecessary, even where the speed had to be, or was, kept up. Mr. Richardson had found it best to use a separate engine for the dynamo, and had described an electrical governor which regulated the speed to give the proper current in the arc-light circuit supplied by a Brush dynamo, thus making it possible to switch out all lamps not actually required, and effecting a saving in carbons, fuel, and labour. These results were obtainable without a separate engine, which was usually an objection, and was at least unnecessary in most factories. Mr. Mordey wished to draw attention to the Brush automatic regulator, with which Mr. Richardson was apparently unacquainted. This instrument, which was very simple, maintained a constant current by means of a variable resistance placed as a shunt across the field-magnet coils of the dynamo. The resistance consisted of piles of thin carbon plates. When the dynamo was doing full work, and was running at the proper speed, or was doing a smaller amount of work at a suitably reduced speed, the circuit of the carbon resistance was broken; but when lamps were switched out, or the speed was increased, the carbon resistance, by means of a solenoid and core, was placed in shunt across the field-magnet coils. Through the medium of its core and a connected lever, the solenoid, which was in the main circuit, closed the shunt across the field-coils formed by the carbon plates, and exerted pressure on the carbon; thus their resistance was varied, the compression being automatically maintained at that which was necessary to give the proper excitation of the magnets for the requirements of the circuit. Mr. Mordey.

Mr. Sydney F. Walker observed that he had not as yet had any occasion to use electrical governors, the best forms of mechanical governor having fully answered his purpose. At the same time he fully recognized the important bearing that electric governors would have upon the future of both electric lighting and the transmission of mechanical power by means of electric currents. He agreed with several of the speakers in the discus- Mr. Walker.

Mr. Walker. sion on the Paper on "Electric Lighting for Steamships," that the mechanical governor had been blamed for irregular speed, when the inefficient lighting, resulting apparently from irregularity of speed, had been due to defects in the electrical portion of the apparatus, more particularly in the case of arc lamps. In his own practice, he had never encountered difficulty in obtaining good results with any well-made engine, provided there was a liberal supply of steam and a sensitive governor. As he understood the matter, there were two causes of variation in the speed of the mechanical motor used to drive the dynamo—namely, variable pressure of steam and a variable load. In the first case, it appeared to him that the mechanical governor, receiving its impulse directly from some moving portion of the engine itself, and geared so that a small increase of speed gave rise to a sufficiently large increase of the speed of the governor balls to quickly check the supply of steam to the cylinder, should be more sensitive than an electric governor receiving its impulse at second or third hand from an electric current forming part of the load, and that in the second case the electrical governor, whose variations coincided with those of the currents that were supplying the lamps, motors, &c., must have a great advantage over a mechanical governor acting at second hand. When it was needed, as the Author had rightly pointed out, it might be in some installations that the engine should vary its speed in respect to the arbitrary requirements of an electric circuit, that might sometimes be in accordance with, and sometimes in opposition to, the variations that would occur in the ordinary way in the speed of the engine; the utility of an electric governor which would do that, was enormously increased. Take the case which the Author had given, of the increased electromotive force required to drive an increased current through the leads to feed an additional number of lamps. He thought no mechanical governor receiving its impulse from the engine could possibly follow the changes that might be induced thereby, since they might be different, under apparently the same conditions. Where, for instance, the magnetism of the field magnets would be largely increased by the passage of the additional current round them, the speed of the motor might need reduction; and yet in another apparently identical case, but where the winding or some other part of the arrangement had been modified, the reverse might take place. With the mechanical governor the tendency was always to reduce speed temporarily on the addition of lamps, in parallel, and to increase speed on lamps being taken off; because, in the one case

the load was increased, and in the other it was reduced. Mr. Walker. He had, however, doubts whether the governor in question, which it must be owned had given remarkably good results, was not too complicated for general use, and whether some simple arrangement might not answer equally as well for practical purposes. He should be extremely sorry to detract from the skill, care and patience that had been shown by the Author of the Paper in working out his apparatus; and it was also perhaps early to point to possible difficulties. Continuous practical work was the only safe test. But he had found by experience that one of the greatest difficulties, in the way of extended commercial application of electrical apparatus, had been the dearth of men in the position of mechanics, enginewrights and others, who would have charge of the apparatus, and on whom any repairs would fall, who had even the smallest practical knowledge of electrical apparatus; and he thought that this difficulty must be very much increased when three such widely differing physical agents as steam, water, and electricity were combined in one small apparatus, whose usefulness entirely depended upon its being always, and at all times, in perfect working order. He also doubted some of the conclusions arrived at by the Author, as to other forms of electrical governors, and his reasons for preferring his own plan. The Author had given a list of the different forms of electrical governors introduced up to the present, and his objections to them. He objected to a motor or magnet actuating the ordinary centrifugal governor, as necessarily complicated. Mr. Walker was unable to follow him in this. He certainly thought that, granted the excellence to which the best forms of centrifugal governors had attained as described by the Author, Mr. Paxman and others in the discussion on the Paper on the "Electric Lighting of Steamships," it was only necessary that the governor should receive its impulse from the variation in the load, instead of from the variation of speed of the engine, for it to fulfil all requirements as efficiently, and with greater simplicity of arrangement, than with the relay cylinder. To the second kind, "in which the armature of an electro-magnet (the coils of which formed part of the circuit to be governed) is connected directly to the regulating valve of the engine," the Author objected, on the ground that they were not sufficiently powerful unless large magnets were used and considerable power absorbed in them. He should be glad to know if the Author made this statement from actual experience, as he could conceive no difficulty in this case, either in constructing the magnet of sufficient power to work the valve direct, or if preferred by means of a differential lever; and in his opinion, if the same care

Mr. Walker. were taken in constructing and fitting the valves that had been taken with that of the Author and others, he should expect an equally good result, while the cost and chances of failure should be considerably reduced. The Author had pointed out that the power available for regulation was the difference of attraction, and not the total pull; but that only meant, either having the apparatus larger, or using a larger coefficient in the multiplying gear. It would be easier, he thought, to make use of the experience gained by engine builders than to strike out a new line, and there were many methods by which the necessary power could be communicated to the regulating valve, by means of electric currents, without so much complication. He believed that some arrangement of an electric motor would present advantages in point of simplicity, economy, and wider range for regulation. With regard to the power absorbed in the governor, it might be well to point out that, however it might be utilized, it must, except in special cases, come from the same source, and that the work done on, or by the different parts of the governor represented so much coal used in the furnace, whether the work were done by an electric current, by the expansion of steam, or by the propulsion of water; so that if with one form a larger magnet and more electrical power were employed, it would be balanced by the power used in some other way in another form. Farther than this, in any installation in which an electric governor was used, the power absorbed by the governor would be but a very small part of the total work done, and a slight additional charge, resulting either in greater simplicity or greater efficiency, would be well expended. One very important point had been mentioned in the discussion on the Paper on the "Electric Lighting of Steamships," namely the danger of having an electro-magnet near an engine, where oil and grease must necessarily be present. With an electro-motor driving the centrifugal governor, the former could be placed out of harm's way in that respect, and there need be no more difficulty in bringing wires to it from the point of consumption than to the solenoid used by the Author. The ability to maintain a constant current, with varied resistance, as in electrotyping baths and in arc-lighting in series, was of undoubted value. About three years ago he had designed an electrical governor for this purpose, similar to the early one of Mr. Richardson. Since the improvement in dynamos, however, a modification of the compound winding, first introduced by Mr. Charles, the electrician to the late firm of Emerson, Murgatoyd and Co., had answered the same purpose. The speed was maintained constant, but the electromotive force at the terminals of the

dynamo rose or fell as lamps were turned in or out, maintaining the current at a uniform strength. Mr. Walker.

Mr. WILLANS, in reply to the correspondence, said that he thought the automatic boiler-feeder which Mr. John Hayes had found so useful, would have worked equally well if an electrical regulator had been employed, although on account of the latter being less affected by changes in steam-pressure than the average centrifugal governor, there would possibly have been less necessity for it. He would not dispute the point as to the relative economy of shunt and compound machines referred to by Dr. Hopkinson. His meaning, when he wrote the paragraph to which Dr. Hopkinson referred, was that if a certain intensity of current round the field magnets gave the cheapest possible magnetic field, it could not be widely varied (as it necessarily was in the case of compound machines arranged to compensate for large constant resistances in the circuit) without some loss. Dr. Hopkinson, however, knew far better than he did how such losses would be compensated by the possibility of closer winding, on account of the smaller proportion of insulating material on the series coils; and as the electrical governor could be employed as well with compound as with shunt machines, and as the compound machines might, when such governors were used, be constructed with a view to economy rather than absolute accuracy, the combination of the two would probably in many cases be the best arrangement of all. He thought that the objection raised by Mr. Walker to the combination of electrical mechanism with the relay working the throttle-valve, on account of the difficulty of finding engine-men "who had even the smallest practical knowledge of electrical apparatus," was rapidly disappearing; the apparatus was in reality much simpler than at first sight it appeared, the electrical part of it being especially simple. The use of a motor as a relay had been fully considered, and designs had been prepared, but on account of its extra complication and certain practical difficulties it had been given up for the present for the simpler water cylinder and valve. Although the power for working the governor all came from the same source, whether the work were done by an electric current, by the expansion of steam, or by the propulsion of water, he thought that Mr. Walker would find a very wide difference between the power required for working, say expansion-gear, by a solenoid direct, and that required for actuating the same gear through the intervention of a relay. An enormous solenoid, comparatively speaking, must be used in the former case, and the power absorbed in the coils would be absorbed at all times. In the latter case the Mr. Willans.

Mr. Willans. power absorbed was inconsiderable until the mechanism was called into action by changes in the light. The power necessary to move the valve might be taken as the same no matter what the agent employed, but that power was trivial compared with the power expended in the solenoid.

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31 March, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Paper by Mr. P. W. Willans on "The Electrical Regulation of the Speed of Steam-engines, and other Motors for driving Dynamos," occupied the evening.

In pursuance of the Notice on the Card of the Meetings it was resolved to adjourn for a fortnight, in order to avoid holding a Meeting on the Tuesday in Easter week.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 1840, Supplemental.*)

"Further Data on Aerial Navigation."

By WILLIAM POLE, F.R.S., M. Inst. C.E.

A FEW years ago the Author submitted to this Institution some remarks on Aerial Navigation,[1] describing what had already been done, and pointing out the influence of recent mechanical improvements on the solution of the problem. Since that time further practical trials of dirigible balloons have been made, of such importance as to deserve mention.

Soon after the introduction of the mode of obtaining electric power by the dynamo machine, one of the most skilful and experienced modern aeronauts, Mr. Gaston Tissandier, conceived the idea that it might form an advantageous motor for the propelling screw of a dirigible balloon,[2] in place of the steam-engine adopted by Mr. Giffard, or the manual power of Mr. Dupuy de Lôme. To test his idea he made a working model, which was shown at the Paris Electrical Exhibition of 1881, and excited much interest. It was a balloon of elongated shape, with pointed ends, having a length of 11½ feet, and a maximum diameter of 4¼ feet, and it was filled with hydrogen gas. Below it was suspended a small dynamo machine, excited by a Planté battery, and turning a screw of 16 inches diameter. The balloon was propelled, through still air, at a speed of 1 metre per second, for upwards of forty minutes; but with increased battery power, and a larger screw, 3 metres per second were obtained for a short time.

Emboldened by the success of this miniature experiment, Mr. Tissandier made a larger model, and subsequently, in conjunction with his brother, Mr. Albert Tissandier, proceeded to manufacture a full-sized structure.

The balloon was formed on the model of those previously used

[1] See Minutes of Proceedings Inst. C.E., vol. lxvii., pp. 369–394.

[2] Full accounts of Mr. Tissandier's experiments will be found in the scientific periodical edited by him, "La Nature," Nos. 428, 468, 504, 540, 542, 543, and also in the "Comptes Rendus" of the Academy of Sciences, October 15, 1883.

by Mr. Giffard and Mr. Dupuy de Lôme; *i.e.*, it was of an elongated shape, with pointed ends, 28 metres (92 feet) long, and 9·2 metres (30 feet) diameter in the middle of its length. It was formed of "percaline," covered by a new varnish which made it perfectly gas-tight. The volume was 1060 cubic metres (37,500 cubic feet). It was filled with hydrogen, manufactured by an improved process, and the ascending power was found to be 1,250 kilograms (=2,760 lbs.).

The weights were given by Mr. Tissandier as follows:—

	Kilograms.	Lbs.
Balloon, with its valves	170	375
Jacket, with the rudder and the suspending cords	70	155
Flexible lateral framing	34	75
Car	100	221
Anchor and guide-rope	50	110
	424	936
Motor, propelling screw and batteries, with liquid to work during 2½ hours	280	620
Two passengers, with instruments	150	331
Ballast	386	851
Margin	10	22
Ascending power	1,250	2,760

The motive power consisted of a Siemens's dynamo, on a new model, made specially in the Paris workshops. It weighed 54 kilograms (120 lbs.), and was capable of furnishing a power of 100 kilogrammetres per second = 1⅓ HP. It is generally understood that 100 lbs. per HP. for such machines is a good ordinary standard, so that this machine was a favourable example. The machine was supported on a cross-bearer attached to the car, which was an open cage of the form of a cube. The dynamo made, at its maximum, 1,800 revolutions per minute, which were reduced to 180 on the screw by spur gearing.

The screw propeller was 2·85 metres (= 9·3 feet) diameter, formed of two helicoidal blades, covered with varnished silk, and stiffened by trussed frames, with tension rods of light steel wire. The screw projected from the car, being fixed on a light shaft supported by the same bearer that carried the dynamo machine. The whole arrangement of the motor and its appurtenances was very ingenious and effective. The action was steady and easy of control.

The original intention was to make use, for the supply of the current, of Faure's accumulators; but after a number of experiments, Messrs. Tissandier were led to the construction of a new

light form of battery with chromate of potash, which gave, weight for weight, a considerable increase of power. This is fully described in "La Nature." It consisted of twenty-four elements, which could be worked either all together, or partially in sets of six, by an ingenious commutator arrangement. The weight of this portion of the apparatus, fully charged for working two and a half hours, was 180 kilograms (400 lbs.), giving 46 kilograms (100 lbs.) for the propelling screw, &c.

On the 8th October, 1883, the balloon was filled with hydrogen gas, prepared by a special process, at Auteuil, near Paris, and ascended at 3.20 P.M. with Messrs. Albert and Gaston Tissandier in the car. The day was calm, there being only a faint breeze on the ground-level, but at 500 metres elevation it had increased to about 3 metres per second (6·7 miles per hour). The balloon was kept generally at about this height above the ground. The screw was set to work, with the full power of the engine, and the movement of translation of the balloon immediately became evident, the aeronauts feeling a fresh wind produced by its motion through the air. The rudder was then brought into action, and the head of the balloon turned towards the wind. In this position it held its own against the aerial current, and remained sensibly immovable for more than twenty minutes over the Bois de Boulogne.

The balloon was afterwards turned to run before the wind, and the effect of setting the screw to work was to increase sensibly the speed, while the rudder gave an unmistakable power to deviate the course to the right or left of the wind's direction; a fact verified by observers on the earth, as well as by the aeronauts in the car.

At 4.35 P.M. the descent was effected with full success in a plain near Croissy-sur-Seine. The balloon remained at anchor the whole night, without any loss of gas, and it was intended to make a second ascent the next day; but the battery had become unsuitable.

The general behaviour of the balloon was satisfactory, but there was a tendency to gyratory movements which required correction.

On the 8th October the experiment was resumed, alterations having been made which fully corrected this tendency. The power of the battery had also been increased, so as to furnish about 1½ HP., the screw making 190 revolutions per minute. The wind blew about 3 metres per second (6·7 miles an hour), but the velocity of the balloon reached 4 metres (13·1 feet per second, or 9 miles an hour), which gave the power of running against the wind. Having this capability, the aeronauts executed a variety of manœuvres in the air; varying their direction, turning about in sharp curves, and so on; finally descending, after two

hours' voyage, at a distance of 25 kilometres from their starting-point. The balloon is said to have been perfectly steady, and to have answered its rudder with great sensitiveness.

Further experiments, also with electric power, have been made by two French officers, Captains Renard and Krebs, who constructed, at the military workshops at Meudon, near Paris, a balloon 50·42 metres (165 feet) long, and 8·40 metres (27·5 feet) maximum diameter. The shape differed from previous ones, in that the largest diameter was not in the middle of the length, but was considerably nearer the front end; the extremities being pointed in the customary way. The volume was 1,864 cubic metres (66,000 cubic feet).

The balloon was fitted with an internal pocket, into which atmospheric air could be forced by a fan ventilator in the car, as designed by Mr. Dupuy de Lôme.

The car was 33 metres (108 feet) long, and 2 metres (6½ feet) high; the object of the great length being probably to act as a keel, and check the tendency to roll.

The motive force was generated in a battery, the construction of which has not been made known. It was divided into four sections capable of being differently combined. It was calculated to develop, in the gross, 12 HP., giving 8·5 HP. on the screw-shaft. The weight, for one gross HP. working an hour, was 19·35 kilograms = 43 lbs., or 68½ lbs. per useful HP. per hour.

The motion of the dynamo was transmitted by spur gearing to the screw, which, contrary to the usual plan, was placed at the *front* end of the car. It was 7 metres (23 feet) diameter, formed of two blades, and was made to unship when required to be out of the way.[1]

The weights were as follows:—

	Kilograms.	Lbs.
Balloon and interior pocket	369	814
Jacket and net	127	280
Car complete	452	997
Rudder	46	101
Screw	41	90
Frames, gearing, and motor-shaft	77	171
	1,112	2,453
Machine	98	216
Battery	436	960
Two aeronauts	140	309
Ballast	214	472
Ascensional power	2,000	4,410

[1] For particulars of these trials see "La Nature," 1884, Nos. 587, 590, and 598.

On the 9th August, 1884, at 4 p.m., the balloon, filled with hydrogen, ascended with the two aeronauts, there being little or no wind. When the screw was started the balloon went ahead, and obeyed the slightest action of the rudder. A distance of about 4 kilometres was run in a southerly direction, after which a detour to the west was made, and finally, the machine was made to return to the place of departure. It turned in a curve of about 300 metres diameter, with an angle of about eleven degrees given to the rudder. In descending it was necessary several times to go backwards and forwards, as in laying a steamboat alongside a pier: these manœuvres were executed with perfect facility, and the landing was effected successfully, precisely in the spot it started from.

The stability of the balloon appears to have been satisfactory; it was only subject, occasionally, to slight oscillations of two or three degrees in the nature of pitching, which were ascribed to irregular motions of the air.

The following data are given in the description:—Distance run, measured on the ground, 7·6 kilometres = 4¾ miles. Time occupied, 23 minutes. Mean velocity, 5·5 metres (18 feet) per second, or 12·3 miles per hour. Number of elements employed, thirty-two. Gross electric power developed, 250 kilogrammetres = 3¼ HP. Probable efficiency of the machine = 0·7. Useful power, exerted on the screw-shaft = 2⅓ HP. Probable efficiency of the screw = 0·7. Power expended in driving the balloon, 125 kilogrammetres per second = 1⅝ HP. Approximate resistance of the balloon, 22·8 kilograms = 50 lbs.

On the 12th September a second ascent was made. There was then a moderate breeze, and when the head of the balloon was turned towards the wind, the propelling power kept it perfectly stationary for some minutes, the screw making 40 revolutions per minute. Another direction was then taken, but by an accident happening, the motor ceased to work, and the balloon drifted with the wind to a spot 5 kilometres away, where it descended safely. This drifting gave the means of measuring the velocity of the wind, which proved to be 20 kilometres (12½ miles) an hour, and this accordingly indicates the speed through the air given to the balloon by its motive power, when it remained stationary—a result corresponding with that of the former trial.

On the 8th November, 1884, other trials were made. The wind was blowing 8 kilometres, = 5 miles, per hour, and the balloon was propelled through the air at the rate of 23·5 kilometres = 14·6 miles per hour. This, therefore, gave a speed of nearly 20 miles

an hour going with the wind, and of nearly 10 miles going against it. The balloon travelled some distance in a northerly direction, then described a semicircle of about 160 metres in diameter, and returned, descending precisely on its point of departure. The motor gave 5 HP. (equal to 3·5 HP. on the screw shaft), the screw making 50 revolutions per minute.

It may now be useful to compare some of the facts furnished by these trials, with the data and the calculations in the Author's former Paper already quoted.

First, as to the ascending power. This was taken in the former Paper, on the ground of Mr. De Lôme's experiments, at about 0·069 lb. per cubic foot, the theoretic power of pure hydrogen being 0·075. Mr. Tissandier's balloon had a capacity of 37,800 cubic feet, and the ascensional power was found to be 2,760 lbs., giving a levity of 0·073 lb. per cubic foot. Messrs. Renard and Krebs's balloon had a volume of 66,000 cubic feet, and an ascending power of 4,410 lbs., giving about 0·066 lb. These correspond fairly with the former figures.

Next, as to the weight of the structure. The weight of Mr. De Lôme's balloon (about 49 feet diameter, and 119 feet long), including the propeller and shaft, was 3,885 lbs.; and, assuming this to be proportional to the surface of the balloon, it would give the weight in lbs. = 0·673 $d\,l$, where d and l are the maximum diameter and length respectively. The corresponding weight of Mr. Tissandier's balloon was 1,036 lbs. = 0·375 $d\,l$. This is remarkably light, one reason being no doubt the omission of the internal air-pocket and its supply-fan, to which Mr. De Lôme attached much importance.

The weight of the same portions of Messrs. Renard and Krebs's balloon, which had the pocket and fan, was 2,453 lbs., giving the weight = 0·53 $d\,l$. Here therefore is clearly an improvement, by lightening the balloon, and so enabling it to carry more power, or more cargo.[1]

The proportion of length to maximum diameter in Messrs. Tissandier's balloon was 3·04, about a mean between Mr. Giffard's, 3·66, and Mr. De Lôme's, 2·43. Messrs. Renard and Krebs have increased the length very materially, namely to six times the

[1] Possibly the Author's assumption that the weight of the structure may be expressed by $B\,d\,l$ (B being a constant) might, when larger balloons and higher speeds come to be used, require to be changed to $B\,d^x\,l$, where x is something rather greater than unity, as the strength of the parts may have to be increased. Hitherto, however, as the text shows, his estimate has been more than sufficient.

maximum diameter, which much augments the carrying-power without proportionally increasing the resistance. The advantage of this will be shown at once by a reference to column 1 of the Table in the former Paper.[1] Although the balloon is only 27½ feet diameter, the available ascending force is increased from 600 to 1,957 lbs., the power of the motor from 3 to 8½ horses, and the maximum speed from 12 to 19 miles an hour.

The reduced diameter, for a given volume, also gives the power of bringing the centre of motive force nearer to the centre of resistance, the importance of which has been alluded to in the Author's former Paper.

If therefore the increased length is not found to bring any counterbalancing disadvantages in construction or working, the capabilities of dirigible balloons will be very largely increased beyond the figures given in the Author's Table.

An estimate may be formed of the speed which, on known mechanical principles, ought to be given to these balloons by a given power applied.

According to the Author's formula (II.) in his former paper, combined with a subsequent one for the coefficient of resistance; if d = maximum diameter in feet, and v = velocity in feet per second, the useful HP. of the engines applied to the screw shaft should be $= \frac{0 \cdot 00193\, d^2 v^3}{7 \times 550}$; or $v^3 = \frac{3850}{0 \cdot 00193\, d^2}$ HP.

In Mr. Tissandier's balloon, $d = 30$, the dynamo is said to have given a *force motive effective* (*i.e.*, estimated probably on the screw-shaft) of 1½ HP. This should give a velocity of 14·9 feet per second. The velocity attained by Mr. Tissandier was 13·1 feet per second, the difference being probably attributable to the small size of the screw.

In Messrs. Renard and Krebs's balloon $d = 27 \cdot 5$. In the two first experiments the HP. exerted on the screw-shaft was $= 2 \cdot 33$; this should give 18·3 feet per second, or 12·5 miles an hour, which is also very near what was attained. In the third trial the HP. was increased to 3·5, which should produce 21 feet per second, or 14·3 miles an hour; the actual speed was 14·6 miles.

The resistance to motion of Messrs. Renard and Krebs's balloon, at the velocity of 18 feet per second, is estimated by them approximately at 50 lbs. The Author's formula, $0 \cdot 000193\, d^2 v^2$, gives 47 lbs.; the excess is no doubt due to the increase of length.

[1] Minutes of Proceedings Inst. C.E., vol. lxvii., p. 386.

It remains to say something of the new power that has been employed in the later trials. It has, as was pointed out by its first proposer, Mr. Tissandier, three great advantages:—

1. It avoids the alarming idea of the proximity of fire to the balloon.

2. It gets rid of the constant change of weight due to the combustion of the fuel, and in some degree (though this may be limited by effective condensation) to the evaporation of the water. And

3. It is so much more easily managed and controlled.

The only question is, at what price these advantages are purchased as regards weight. The data on this point are not sufficiently full and clear for making an accurate comparison between the two systems. Probably the weight of the engine per HP. may be assumed to be pretty much the same in both, but the weight of the power-supply seems at present much the greater with electricity. The weight of Messrs. Tissandier's battery, charged for working 1½ HP. for 2½ hours, is given at 180 kilograms, or 400 lbs.; this is 107 lbs. per useful HP. per hour. Messrs. Renard and Krebs give the weight of their battery per gross HP. per hour at 19·35 kilograms = 43 lbs., which is 61 lbs. per useful HP. per hour. But the weight of fuel and water for a steam-engine, taking fair advantage of an air condenser (as explained in the Author's former Paper) would be only 10 or 12 lbs. This makes, of course, a great difference in the power-supply that can be carried. It must, however, be borne in mind that the use of electric power for this purpose is quite in its infancy, and that improvements may be reasonably expected.

It is right to testify to the meritorious efforts of the Messrs. Tissandier, who were the first to introduce this power. They not only completed their balloon at their own expense, together with all the electrical appliances and the apparatus for making the gas, but they built extensive workshops and plant for the purpose. Their enterprise and public spirit in the matter deserve high commendation.

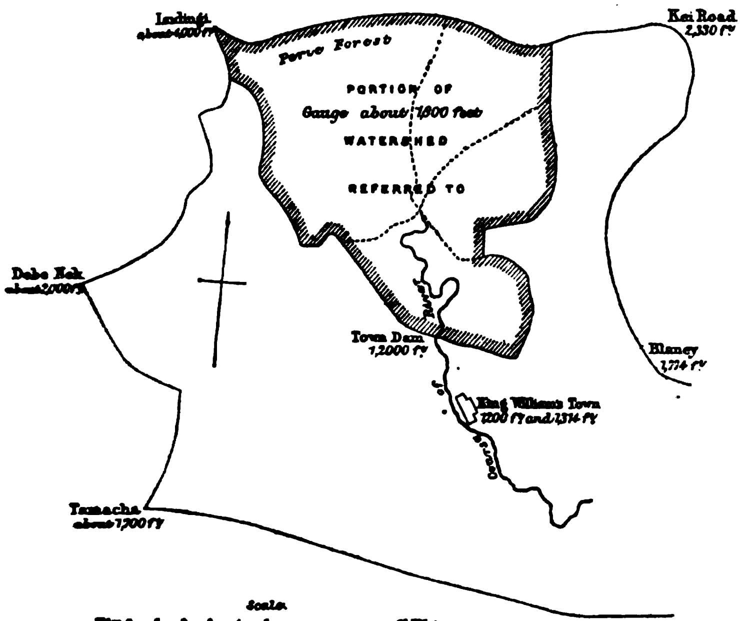
These experiments, combined with the former ones, have amply sufficed to establish aerial navigation by balloons as no longer a hypothetical possibility, but an accomplished fact, taking its rank with any other mechanical process in the early stages of its career. Moreover, the experimental results attained have served not only to bear out the anticipations formed on this subject by theoretical reasoning, but to show that by ingenious invention and contrivance, these anticipations may be considerably exceeded.

(*Paper No. 2046.*)

"The River Buffalo; total Flow at the Town Dam, King William's Town, Cape of Good Hope, from June 1880 to March 1883 compared with the Rainfall."

By William Blomefield Tripp, M. Inst. C.E.

In 1882 a Paper was contributed by the Author to the Cape Town Philosophical Society, on "The River Buffalo; its Watershed and Flow, in connection with the Rainfall."[1]



N.B.—The elevation at the Town Dam should be 1,260 feet instead of 12,000, as given in the woodcut.—Sec. Inst. C.E., 4 August, 1885.

The River Buffalo.

Since that time the observations have been continued, and the results worked out to a greater degree of completeness; while the

[1] Minutes of Proceedings Inst. C.E. vol. lxxiii. p. 414.

more extended series of rainfall observations made under the Meteorological Commission, Cape Town, have been added.

Table I., giving the details of all falls of rain of 0·50 inch and upwards in twenty-four hours; and Table II., of the rainfall and flow of the river, with the proportion of the former flowing off, at the Botanic Gardens, King William's Town, during the thirty-four months above specified, are appended to this Paper.

1. *Watershed.*—The general features of the main watershed of the Buffalo have been already described in the Paper above referred to. That portion to which the present observations refer, is shown in the annexed map, taken from the map of the Eastern Districts of the Cape Colony, compiled in the Surveyor-General's office at Cape Town. It consists of the upper parts of the drainage-areas of some of the principal tributaries; in fact, the whole of that portion of the watershed draining into the river above the Town Dam, which is situated about 2½ miles above King William's Town, and 33 miles from the Indian Ocean. This portion has an area, as measured on the aforesaid map, of about 105 square miles.

The lowest point of this part of the watershed at the Town Dam, at its southern extremity, has an elevation of about 1,260 feet above the sea, and the dividing ridges around it rise to their greatest elevation at the north-west angle, where the Isidingi attains an elevation of about 4,000 feet.

2. *Rainfall.*—Those stations which, from their position in the neighbourhood, are the most suitable for the purpose of ascertaining the mean rainfall over the area above mentioned, are five in number, namely, two at King William's Town, about 1,200 and 1,314 feet above the sea respectively, the mean of the rainfall at these stations being taken as the rainfall at that point; one station at Kei Road, 2,330 feet above the sea, at the extreme north-east point of the main watershed; one in the heart of the Perie Forest, in the valley of the main feeder of the Buffalo, at an elevation of about 1,800 feet, established in December 1880, and with gaps subsequently in the record; and one at Blaney, 1,774 feet above the sea-level, established in September 1882, at the south-east extremity on the boundary ridge of the main watershed.

The depths of rain have been extracted from the reports of the Meteorological Commission; and from those quoted, as well as from those taken all over their south-east district, the average results of which for five years and upwards are given in the report for 1883, it appears that the amounts do not vary to any very great extent at the several stations. The totals for the months during which the rainfall was recorded at the three last-mentioned

stations respectively, when compared with that registered at King William's Town for the same months, show a proportion, at Blaney, of about 1·07; at Kei Road, of 1·38, and at Perie Forest of 1·44. These proportions are, however, by no means constantly maintained, as the rainfall is most irregular. The seasons for this period were for the most part dry and abnormal, there having been an almost complete drought during the winter of 1880, and the deficiency was only partially made up by the heavy rains of the spring following. The chief fall in 1881–2 occurred during the winter, while both in the 1881–2 and 1882–3 divisions of the period, as arranged in the Tables, the springs and summers were very dry. This result is contrary to that exhibited under the usual sub-tropical character of the seasons; at King William's Town from an average of fifteen years, out of a total of 26 inches yearly, about 9½ inches fall during the summer quarter, from January to March; nearly 8 inches in the spring, from October to December, and about 4¼ inches each in the autumn and winter, namely, from April to June, and from July to September respectively. The general character of the rainfall may be gathered from the analysis given in Table IV. of the registers kept by the Author at the Botanic Gardens, King William's Town. Here, on a total of two hundred and eighty-three days, 70 inches of rain were registered, 30·25 inches of which, recorded on two hundred and forty-two days, were made up of falls under 0·50 inch in twenty-four hours; 19·88 inches on twenty-eight days from 0·50 inch to 1 inch, and 19·87 inches on thirteen days, of falls of 1 inch and upwards. The heaviest fall on any one day was 2·04 inches, recorded at 9 A.M. on the 18th of November 1880; while 3·11 inches fell in the forty-eight hours ending the 4th of March 1883, and 3·10 inches in the forty-eight hours ending July 26th, 1881. The highest monthly totals were 5·43 inches in March 1881; 5·22 inches in March 1883, and 4·55 inches and 4·54 inches in October 1880 and July 1881 respectively.

The depths of rain, adopted for the calculation of the quantity falling over the whole area of the watershed, are the means of those taken at the above-named stations as they were successively established, which give as the greatest monthly totals, 6·05 inches for March 1881, 5·27 inches for March 1883, and 4·825 inches for January 1881. No rain was recorded in July, and only 0·020 inch was adopted for June 1880; 0·152 inch for June 1882, and 0·155 inch for September 1880. The aggregate depth adopted for the thirty-five months comes to 81·462 inches,

or a total fall over the area of 105 square miles of nearly 20,000,000 cubic feet, and a monthly mean of 584,500,000 cubic feet, that for the 1881–2 division being above, and that for 1880–1, and still more 1882–3, being below this average.

3. *Division of the River-volume into two parts.*—The rivers and streams of South Africa are to a peculiar degree locally, and even legally, recognized as belonging either to the perennial or to the intermittent class. The latter are fed only by that portion of the rainfall which at once flows off the surface and down the channel in the form of storm-waters or floods, the river-beds being sometimes dry for many months together, and even used as roads during the periods between the occurrence of rain-storms. Rivers of the former class are kept permanently flowing by that portion of the rain which, after sinking into the ground and being partly absorbed by the roots of vegetation, or held in suspension by capillary attraction, issues again from the earth in the form of more or less permanent springs.

The Buffalo belongs to the perennial class, a result which the Author believes is mainly due to the fact that the area around its chief sources is still clothed with forest and bush. In Table I. the total volume of the river is divided into ordinary flow and flood discharge.

4. *Ordinary Flow.*—This consists of that portion of the total volume which is due to springs, which, however, as they cannot be tracked to their source, may possibly arise from rain falling at points outside their proper drainage area, the flow from which, being soon heightened by storms of rain, includes a certain increment from this source; the result, however, of moderate falls of rain, distributed over a considerable number of days, does not always immediately appear in a corresponding alteration of the mean flow, the soil over the greater portion of the drainage area being sandy and absorptive, and the effect of evaporation in a country with the climatic conditions of the Cape Colony being very considerable.

The ordinary flow is of course by far the more important element to be considered in engineering questions relating to such purposes as the working of mills, or the supply of water to towns, for which purposes it may be usefully employed at much less cost than would be necessary in the case of such undertakings being dependent on storm-waters; still, these latter have their uses, and in some parts of the Colony, where on each occasion of a storm they overflow a large portion of cultivable land, they deposit fertilizing materials.

The ordinary flow varied over this period from 87 cubic feet to

2,880 cubic feet per minute, equal to from 125,000 to 4,147,000 cubic feet per day, these extremes occurring in February 1882 and October 1880 respectively, the variation being therefore as from about 1 to 33. The mean was 933·8 cubic feet per minute, or 1,344,700 per day. The highest monthly totals were, 105,400,000 cubic feet in November 1880; 92,900,000 in December 1880, and 82,600,000 in January 1881. There was a continuous yearly decrease under this head owing to the drought, particularly as it occurred to a large extent in the summer seasons, when its effect would of course be most felt.

5. *Flood-Discharge.*—The Author has endeavoured to estimate both the highest ratio of discharge per minute above the ordinary flow, and also the total monthly volume under this head.

The former varied from 600 to 285,000 cubic feet per minute. Occasionally the floods rise much higher. The highest monthly totals were, 858,200,000 cubic feet in March 1883, and 416,900,000 and 412,600,000 cubic feet in March and February 1882 respectively; monthly mean was about 90,700,000 cubic feet; the mean for the 1880–1 division was below, and that for the 1882–3, and the 1881–2 divisions, above this quantity.

The total ordinary flow is to the flood-discharge as nearly 1,390½ to nearly 3,084½, or as from about 1 to 2¼.

6. *Total Volume.*—This is the sum of the ordinary flow and flood-discharge. The highest total for any one month was about 918,900,000 cubic feet in March 1883; the next being about 465,400,000 in November, 1880, and 450,400,000 in March 1882; the monthly mean was 131,600,000 cubic feet; that for 1882–3 and still more 1881–2 being above, and that for 1880–1 below the average. The variation was from a minimum of about 6,300,000 cubic feet in September 1880, to the above maximum, or as from about 1 to 147.

7. *Proportion of Rainfall flowing off the Ground.*—Under the head of ordinary flow, this proportion does not appear to vary in any regular manner, when the rainfall is not too small for comparison. The proportion, however, discharged by floods is increased considerably when the rainfall is copious, and comes in the form of heavy falls, distributed over short periods of time.

The proportion of the total volume follows that of the ordinary flow when the rainfall is moderate, but when the flood-discharge is heavy, a preponderating influence is exercised by it over the total result. Under the ordinary flow, the proportion varied from 0·011 in February 1882 to 0·157 in September 1881; omitting from consideration the months of July 1880, when no rainfall was recorded,

and June with only 0·020 inch, also June 1882 and September 1880, for which months only 0·152 inch and 0·155 inch respectively have been adopted, as the comparison of the flow with the rainfall under such conditions would give a fictitious result. The mean over the whole period was 0·070, or about one-fourteenth of the rainfall.

There was no flood-discharge in September 1880 and June 1882; the proportion varied from this result to a maximum of 0·668 in March 1883, the mean being 0·155, or about one-sixth.

The total proportion flowing off from all sources during the whole period, disregarding again the months of June and July 1880, varied from 0·019 in September 1882, to 0·715 in March 1883; the total result being a proportion of 0·225, or between one-fifth and one-fourth of the rainfall. The proportions for March 1881, when the heaviest rainfall was recorded, were, ordinary, 0·042; flood, 0·195; total, 0·237. During this month 4·62 inches of rain were registered at the Botanic Gardens, King William's Town, in falls of 0·50 inch and upwards, in twenty-four hours, the greatest depth in falls on consecutive days being 3·05 inches, which were recorded on the mornings of the 17th, 18th, and 19th; but the total in the forest only slightly exceeded that at King William's Town. The proportions for March 1883, the next wettest month, were 0·047, 0·668, and 0·715 respectively, this high proportion being due to the heavy fall from the 3rd to the 7th, during which period 3·43 inches were measured at the Gardens, 3·11 inches of which were registered on the 3rd and 4th. During this month 4·59 inches were due to falls of 0·50 inch and above, while the fall in the forest was 1·32 inch, or nearly 30 per cent. over that at King William's Town, and of this doubtless a large proportion flowed down the river. The proportions for July 1881, when 3·97 inches were registered at the Gardens on the 25th, 26th, and 27th, 3·10 inches of which fell in forty-eight hours, were 0·050, 0·135, and 0·185.

The Paper is accompanied by a map, from which the figure in the text has been engraved.

APPENDIX.

TABLE I.—DETAILS of FALLS of 0·50 INCH of RAIN and UPWARDS in TWENTY-FOUR HOURS at the BOTANIC GARDENS, KING WILLIAM'S TOWN.

Year and Month.	Total Rainfall during Month.	No. of Days with Rain.	Depth on Consecutive Days.	No. of Days.	Falls of 0·50 in. and over.	Date when Registered.	Year and Month.	Total Rainfall during Month.	No. of Days with Rain.	Depth on Consecutive Days.	No. of Days.	Falls of 0·50 in. and over.	Date when Registered.	Year and Month.	Total Rainfall during Month.	No. of Days with Rain.	Depth on Consecutive Days.	No. of Days.	Falls of 0·50 in. and over.	Date when Registered.	Year and Month.	Total Rainfall during Month.	No. of Days with Rain.	Depth on Consecutive Days.	No. of Days.	Falls of 0·50 in. and over.	Date when Registered.
1880	Ins.		Ins.		Ins.		1881	Ins.		Ins.		Ins.		1882	Ins.		Ins.		Ins.		1883	Ins.		Ins.		Ins.	
Oct. .	4·55	17	1·82	5	0·60	8th	Apr. .	1·88	8	1·63	4	0·78	16th	Mar. .	2·65	12	1·07	4	0·73	1st	Feb. .	1·24	7	1·04	4	0·81	5th
,, .	..	..	..	..	0·53	11th	May .	1·26	9	0·73	3	0·55	18th	,, .	..	..	0·88	2	0·64	13th	Mar.	5·32	11	3·43	5	1·90	3rd
,, .	..	..	1·77	4	1·39	23rd	June	2·38	8	1·77	2	1·27	21st	Apr. .	3·11	9	1·88	4	1·34	3rd	,, .	..	..	..	..	1·21	4th
Nov. .	3·88	11	2·17	2	2·04	18th	,, .	..	..	..	..	0·50	22nd	May .	4·23	14	0·97	1	0·97	1st	,, .	..	..	0·70	1	0·70	12th
Dec. .	1·97	8	0·79	1	0·79	25th	July.	4·54	8	4·14	4	1·49	25th	,, .	..	..	1·64	3	1·22	14th	,, .	..	..	0·82	2	0·78	14th
1881							,, .	..	..	..	..	1·61	26th	Aug.	1·25	5	1·05	2	0·85	12th							
Jan. .	3·02	12	0·96	2	0·78	21st	,, .	..	..	..	..	0·87	27th	Sept.	2·40	9	1·79	1	1·79	30th							
,, .	..	..	0·95	4	0·83	30th	Aug.	1·66	8	1·33	4	0·80	26th	Nov. .	1·53	9	0·63	4	0·52	30th							
Mar. .	5·43	13	1·59	3	0·94	4th	Sept.	1·83	12	1·30	6	0·78	19th	Dec. .	3·57	12	1·40	5	1·04	13th							
,, .	..	..	..	..	0·63	5th	Nov. .	2·39	11	1·78	2	1·77	4th	,, .	..	..	1·00	3	0·66	21st							
,, .	..	..	3·05	3	1·80	17th	1882							,, .	..	..	0·77	1	0·77	30th							
,, .	..	..	..	..	0·71	18th	Feb. .	2·88	10	0·97	3	0·50	16th	1883													
,, .	..	..	..	..	0·54	19th	,, .	..	..	0·77	1	0·77	21st	Jan. .	1·91	12	1·64	9	0·55	20th							

	Inches.		Days.
Total	39·75	in	41
	Inches.		Days.
Falls of 1 inch over . . .	19·87	,,	13
Falls of 0·50 inch over . . .	19·88	,,	28
Falls below 0·50 inch . . .	30·25	,,	242
Total rainfall .	70·00	,,	283

TABLE II. THE RIVER BUFFALO. TOTAL FLOW at the
from June 1880 to May 1881,

Date.	Rainfall.						Ordinary	
Year and Month.	Mean at King William's Town.	Kei Road.	Perie Forest.	Blaney.	Mean adopted.	Total over Watershed of 105 Square Miles.	Minimum Rate per Minute.	Mean Rate per Minute.
	Inches.	Inches.	Inches.	Inches.	Inches.	Million cubic feet.	C. F.	Cub. feet.
1880								
June . .	0·040	None	No returns	No returns	0·020	4·9	250	580
July . .	None	None	„	„	None	None	165	185
August .	0·695	0·57	„	„	0·632	154·2	170	184
September	0·155	Gauge broken	„	„	0·155	37·8	120	145
October .	4·560	2·25	„	„	3·405	830·6	100	1,960
November	4·020	5·35	„	„	4·685	1,142·8	2,000	2,440
December	2·125	4·21	3·68	„	3·338	814·3	1,650	2,080
1881								
January .	3·015	6·31	5·15	„	4·825	1,177·0	1,120	1,850
February.	0·885	3·32	1·69	„	1·965	479·3	980	1,420
March .	5·410	7·23	5·51	„	6·050	1,475·8	1,000	1,370
April. .	1·920	1·75	No returns	„	1·835	447·6	851	1,100
May . .	1·200	0·94	„	„	1·070	261·0	765	850
	24·025	31·93	Incomplete 16·03	„	27·980	6,825·3	100	1,180
1881								
June . .	2·265	2·92	No returns	No returns	2·592	632·3	620	1,215
July . .	4·170	3·83	„	„	4·000	975·7	660	1,100
August .	1·580	2·39	„	„	1·985	484·2	1,000	1,550
September	1·775	1·59	1·81	„	1·725	420·8	1,170	1,530
October .	0·820	1·23	1·51	„	1·187	289·6	325	850
November	2·220	2·37	2·12	„	2·237	545·7	245	420
December	0·380	2·09	2·25	„	1·573	383·7	97	430
1882								
January .	0·845	1·33	1·83	„	1·335	325·7	99	280
February	2·910	4·60	4·63	„	4·047	987·2	87	260
March .	2·695	3·01	3·16	„	2·955	720·8	600	750
April .	2·995	3·99	4·79	„	3·925	957·4	510	1,260
May . .	4·185	4·39	3·91	„	4·162	1,015·3	560	1,430
	26·840	33·74	Incomplete 26·01	„	31·723	7,738·4	87	926

TOWN DAM, KING WILLIAM'S TOWN, CAPE COLONY, COMPARED with the RAINFALL.

Flow.		Flood Discharge.				Total.	Proportion of Rainfall Flowing off $= \frac{\text{Discharge}}{\text{Rainfall}}$.		
Maximum Rate per Minute.	Total.	River in Flood.	Highest Rate per Minute.	Date.	Total.		Ordinary.	Flood.	Total.
C. F.	Million Cub. feet.	Days.	Cub. feet.		Million Cubic feet.	Million Cubic feet.			
930	25·0	1½	1,000	15th	1·1	26·1	Rainfall too small for comparison	0·221	..
219	8·3	1½	600	15th	6	8·9	No rainfall recorded.		
198	8·2	3	1,000	23rd	1·7	9·9	0·053	0·011	0·064
170	6·3	No Flood Discharge				6·3	Rainfall too small for comparison	None	..
2,880	87·5	8	14,000	25th	41·4	128·9	0·105	0·050	0·155
2,860	105·4	12	85,000	21st	360·0	465·4	0·092	0·315	0·407
2,475	92·9	15	7,000	27th	50·4	143·3	0·114	0·062	0·176
2,840	82·6	8½	7,000	22nd	37·1	119·7	0·070	0·032	0·102
2,580	57·3	4	6,000	1st	14·0	71·3	0·120	0·029	0·149
1,730	61·2	12	85,000	18th	288·0	349·2	0·042	0·195	0·237
1,400	47·5	6	7,000	16th	30·2	77·7	0·106	0·068	0·174
1,160	37·9	2	5,000	19th	7·2	45·1	0·145	0·028	0·173
2,880	620·1	73½	85,000	..	831·7	1,451·8	0·091	0·122	0·213
1,680	52·5	4	10,000	22nd	23·0	75·5	0·083	0·036	0·119
2,300	49·1	7	30,000	27th	131·1	180·2	0·050	0·135	0·185
2,475	69·2	3	8,000	28th	17·3	86·5	0·143	0·036	0·179
2,280	66·1	4	3,000	22nd	8·6	74·7	0·157	0·021	0·178
1,360	37·9	4	2,000	24th	5·4	43·3	0·131	0·019	0·150
680	18·1	7	9,000	6th	34·6	52·7	0·033	0·064	0·097
1,030	19·2	2	3,000	11th	4·3	23·5	0·050	0·011	0·061
700	12·5	7½	12,000	3rd	57·2	69·7	0·038	0·176	0·214
900	10·5	4	285,000	28th	412·6	423·1	0·011	0·418	0·429
1,000	33·5	6	285,000	1st	416·9	450·4	0·047	0·578	0·625
2,100	54·4	5	15,000	4th	44·3	98·7	0·057	0·046	0·103
2,200	63·9	7	9,000	17th	31·3	95·2	0·063	0·031	0·094
2,475	486·9	60½	285,000	..	1,186·6	1,673·5	0·063	0·153	0·216

TABLE II. (*continued*).—THE RIVER BUFFALO. TOTAL FLOW at
from JUNE 1882 to MARCH 1883,

Date.	Rainfall.						Ordinary	
Year and Month.	Mean at King William's Town.	Kei Road.	Perie Forest.	Blaney.	Mean Rainfall adopted.	Total over Watershed of 105 Square Miles.	Minimum Rate per Minute.	Mean Rate per Minute.
1882	Inches.	Ins.	Inches.	Inches.	Inches.	Million Cubic feet.	C. F.	Cub. feet.
June . .	0·005	0·45	None	No returns	0·152	37·1	339	600·0
July . .	0·620	1·54	No returns	”	1·080	263·5	240	320·0
August .	1·205	1·68	”	”	1·442	351·8	165	330·0
September	2·565	3·17	2·83	2·87	2·859	697·4	178	260·0
October .	0·720	0·42	1·09	0·63	0·715	174·4	244	520·0
November	1·550	2·72	3·44	1·85	2·390	583·0	166	430·0
December	3·430	1·78	3·77	2·77	2·938	716·7	324	560·0
1883								
January .	1·830	2·93	3·94	2·51	2·802	683·5	266	930·0
February	1·105	2·25	3·41	1·68	2·111	514·9	509	1,200·0
March .	4·890	5·10	6·21	4·88	5·270	1,285·5	480	1,360·0
	17·920	22·04	Incomplete 24·69	Incomplete 17·19	21·759	5,307·8	165	647·8
1881–2 .	26·840	33·74	Incomplete 26·01	No returns	31·723	7,738·4	87	926·4
1880–1 .	24·025	31·93	Incomplete 16·03	”	27·980	6,825·3	100	1,179·6
TOTALS	68·785	87·71	66·73	17·19	81·462	19,871·5	87	9,33·8
	Monthly means . . . . Rainfall = 584·5						Ordinary	

the TOWN DAM, KING WILLIAM'S TOWN, CAPE COLONY, COMPARED with the RAINFALL.

Flow.		Flood Discharge.				Total.	Proportion of Rainfall Flowing off = Discharge / Rainfall		
Maximum Rate per Minute.	Total.	River in Flood.	Highest Rate per Minute.	Date.	Total.		Ordinary.	Flood.	Total.
C. F.	Million Cubic feet.	Days.	Cub. feet.		Million Cubic feet.	Million Cubic feet.			
1,400	25·9	No Flood Discharge				25·9	Rainfall too small for comparison	None	..
560	14·3	2	2,000	23rd	2·9	17·2	0·054	0·011	0·065
660	14·7	2½	1,500	3rd	2·3	17·0	0·042	0·006	0·048
560	11·2	2	1,500	9th	1·8	13·0	0·016	0·003	0·019
858	23·2	7	15,000	2nd	75·6	98·8	0·013	0·044	0·057
800	18·6	3½	2,000	16th	4·3	22·9	0·032	0·007	0·039
850	25·0	6½	9,000	15th	27·7	52·7	0·035	0·039	0·074
2,250	41·5	5½	15,000	23rd	54·4	95·9	0·061	0·079	0·140
2,000	48·4	6	9,000	5th	38·9	87·3	0·094	0·075	0·169
2,260	60·7	8	170,000	5th	858·2	918·9	0·047	0·668	0·715
2,260	283·5	43	170,000	..	1,066·1	1,349·6	0·053	0·201	0·254
2,475	486·9	60½	285,000	..	1,186·6	1,673·5	0·063	0·153	0·216
2,880	620·1	73½	85,000	..	831·7	1,451·8	0·091	0·122	0·213
2,880	1,390·5	177	285,000	..	3,084·4	4,474·9	0·070	0·155	0·225
flow = 40·9		Flood discharge = 90·7				Total volume 131·6			

(*Paper No. 2049.*)

"The Cape Government Railways."

By William George Brounger, M. Inst. C.E.

The past few years have witnessed the construction of a somewhat extensive system of railways in the Colony of the Cape of Good Hope. These lines of railway have been carried out on the 3 feet 6 inches gauge, and include three principal divisions converging towards the Diamond Fields; namely, the Western system, the Midland system, and the Eastern system. The general direction of the Western system is north-east, crossing the rivers forming the main drainage of the country, and intervening ridges, and the bridges are consequently both numerous and important. The Midland system runs north, following chiefly the main drainage of the country; while the Eastern system is characterized by its severe gradients and curves. The country occupied by these systems of railway, and the course pursued by the lines, is shown in the accompanying map of the Cape Colony, Plate 11.

The maximum elevation above sea-level attained on the Western system is 4,572 feet, and on the Eastern system 5,446 feet.

Gradients and Curves.—The percentages of different gradients and level on the several systems are as follows, the percentage being in each case that of the mileage of the whole system:—

—	1 in 40.	1 in 40 to 1 in 50.	1 in 50 to 1 in 60.	1 in 60 to 1 in 80.	1 in 80 to 1 in 100.	Over 1 in 100.	Level.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Western system .	4·06	1·84	3·00	11·67	12·45	54·64	12·32
Midland „ .	9·30	4·70	4·50	13·96	10·07	40·46	17·00
Eastern „ .	17·11	20·77	7·87	11·64	7·54	18·37	16·67

The aggregate lengths of curves of different radii on the several systems are:—

—	Total Length of System.	Radius in Chains.					
		5.	5 to 6.	6 to 10.	10 to 15.	15 to 40.	Over 40.
	Ms. Ch.	Ms. Ch.	Ms. Ch.	Ms. Ch.	Ms. Ch.	Ms. Ch.	Ms. Ch.
Western system .	642 60	0 75	1 75	12 33	7 26	60 75	49 72
Midland „ .	589 13	..	..	26 51	28 26	78 68	16 31
Eastern „ .	291 65	1 19	9 25	33 15	15 62	52 40	10 63

Bridges and Culverts.

Owing to the difficulty in procuring good bricks, the importance of time, and the scarcity of skilled labour, iron superstructures, even in the case of bridges of small span and open culverts, have been largely employed. Arches, however, have been resorted to more extensively on the Eastern system. The character of masonry employed has varied between fitted and coursed rubble, and block-in-course, according to the nature of the stone available, ashlar having, as a rule, been avoided. Cement has been largely employed instead of lime for mortar, owing, not only to the difficulty in obtaining the latter of good quality, but to the saving of cost of carriage consequent upon the much larger admixture of sand which the former will bear.

In some cases of rivers which bring down trees and heavy drift during floods, a plate-diaphragm stiffened by T or L iron between the two cylinders forming each of the piers, has been adopted in lieu of open bracing; this gives the effect of solid piers, and saves them from the strain which might result from large accumulations of heavy drift.

The nature of the country traversed is shown by the following statistics of waterway on the respective lines and systems.

Name of line or section.	Waterway per mile. Feet.
Worcester to Beaufort West	53·0
Western system	38·0
Zwaartkops to Graaff-Reinet	17·0
Midland system, including bridges over tidal rivers	24·0
„ „ without „ „ „	20·0
First 50 miles of the Eastern line	6·6
Whole Eastern system	30·0

On the Eastern system there are eleven bridges of 100-feet opening and upwards, with a total waterway of 1,798 feet. On the

Midland there are, including those across tidal rivers, fourteen bridges with a waterway of 4,229 feet; and on the Western, twenty-one such bridges with a waterway of 5,743 feet. All the bridges are under bridges, as over bridges have only been employed in exceptional cases, not exceeding half-a-dozen throughout the Colony.

Earthworks.

The formation width varies on the different systems, and under varied circumstances from 15 to 18 feet, the smaller width having been adopted in short cuttings with but little drainage. The slopes employed have, except in the case of rock and shale, generally been 1 to 1 for cuttings, and 1½ to 1 for embankments.

Fencing.

Fencing, as a general rule, has not been provided as a part of the railway, except in crossing cultivated ground, which forms a small percentage, or where the lines traverse land which was previously enclosed, which also forms a small proportion of the whole. Cattle are supposed to be prevented straying on the line by the herdsmen. In the case of freehold property, the amount of compensation paid for expropriation covers this risk of loss, and in the case of quit-rent, the Government is entitled to take land and materials without compensation. Nevertheless it has in some instances contributed a portion of the expense of proprietors who are prepared to bear the other part.

Permanent Way.

The weight of rails was fixed by the Government upon the recommendation of the Chief Inspector of Public Works, prior to the passing of the Acts of Parliament; but Mr., now Sir, Charles Hutton Gregory, K.C.M.G., when appointed Consulting Engineer, strongly urged the use of a heavier section, and an increase in this direction to 45 lbs. was, after the supply of a small portion of the original weight, accordingly adopted. Steel of the same section is employed in the cases of gradients of 1 in 70 and steeper, also generally for the outer rail of curves of 10 chains or less radius. This section was employed for the lines sanctioned by Parliament in the years 1873-4, including the few miles laid with

40-lb. rails. The rails are spiked or bolted to creosoted Baltic sleepers, 7 feet by 9 inches by 4½ inches, and fished between the sleepers.

With a view to check the tendency to spread of gauge round the sharp curves of the Hex River Mountain on the Western system, bowl sleepers of Livesey's pattern for a few miles of road were ordered for the sake of the wrought-iron tie; all the different kinds of fastenings employed being found to yield in the case of wooden sleepers, even where hard wood was employed, though the latter checks the tendency to some extent. This piece of road has answered well under a very trying traffic. Most of the sleepers are of cast iron, but a length of 1 mile is laid with wrought iron, and of the latter not a single sleeper has had to be replaced; many of the former, however, are broken in the process of packing. The rails ordered for the last extensions, about 562 miles, are 60 lbs. in weight, all of steel, the fastenings being of the same character as for the lighter rails, while the wooden sleepers for the heavier rails are 7 feet by 10 inches by 5 inches.

In consequence of the difficulty and uncertainty in obtaining wooden sleepers, the increase of their price, and delay in procuring them, it was decided to try iron sleepers on a more considerable scale, and wrought-iron trough sleepers for 36½ miles, and wrought-iron bowl sleepers for 73½ miles, both of Livesey's patterns, have been laid down. As these sleepers have only recently been brought into use, it would be premature to say much as to the result of experience; there are, however, certain points which are palpably evident. First, both kinds require careful packing. In the case of the bowls, if this is not done, they are apt to get out of level transversely, and the result is a cant which throws the line out of gauge.

In the second place, special care is essential in the manufacture of both kinds, particularly in the fixing of the jaws, otherwise the gauge is affected; and where irregularity occurs in the spacing of holes in the tie-bars, play is given on curves with bowls by placing the cotter on the inside, instead of the outside of the bowl, and where much play is required, as on very sharp curves, this is done with both bowls. With the iron trough sleepers, it is desirable that special ones should be provided for sharp curves, with allowance for play, such sleepers having unmistakably distinctive marks to prevent confusion, or otherwise some safe means of adjusting the jaws for gauge.

Thirdly, more care is requisite as regards ballast, and this has been a source of some trouble. It is undesirable that ballast should

be coarse for these sleepers; but it is often difficult to obtain it fine, it being sometimes necessary to use broken stone for top as well as bottom ballast.

In many parts of the country disintegrated shale has been employed as top ballast, under which circumstance it has been found desirable to have a bottom layer of stone for the sake of drainage, and to give a substantial bed. This disintegrated shale has been collected from the beds of rivers, the waters of which carry away the finer portion, and where it occurs, stone suitable for the substratum is generally found in the immediate vicinity of the line.

Various kinds of timber have been tried with a view to test their durability as sleepers, this course having been adopted more than twenty years ago, on the completion of the Wellington line. Several varieties from colonial forests have given favourable results, but their cost has hitherto been prohibitory. Some timber obtained from the Island of Madagascar, of a bright pink colour, proved durable, but difficulty has attended its export. The timber which has hitherto proved the most durable is that of the camphor tree which has been taken up perfectly sound throughout both heart and sapwood, after having been in the ground twenty years, without any preparation; and the Government is accordingly about to make plantations of this tree, which, under favourable conditions attains a large size in the Colony.

A variety of fastenings has been employed for the attachment of the rails to wooden sleepers, but preference is given to dog spikes. Where bolts are employed their renewal is attended with inconvenience when inserted from below; and, in practice, the platelayers are apt to omit the nut when the bolt is inserted from above. Wooden cleets or chocks butting up against the rail and spiked to the sleepers, have been used with advantage to resist the outward strain on curves. Play of gauge has generally been given round curves to the extent of from $\frac{1}{4}$ to $\frac{3}{8}$ inch; but the tendency in maintenance is in the direction of an increase on this allowance.

Rolling Stock.

The engine, carriage, and wagon stock provided for the whole of the three systems, consist of two hundred and thirty-one engines, two hundred and three tenders, three hundred and ninety-nine carriages, or vehicles for coaching traffic; three thousand five hundred and three wagons, including brake vans, and twenty-eight travelling cranes, and breakdown vans.

The engines may be divided into the following classes:—

1. Engines having six coupled wheels, 38 inches in diameter, and two Bissel trucks, one truck under the fire-box, and the other in front of the cylinders, which latter are 15 inches in diameter, with a length of stroke of 20 inches; these engines weigh 29 tons in full working order, including 600 gallons of water in side tanks. Of these there are on the Western system, two engines; Midland system, fifteen; and Eastern system, eight engines.

2. Engines having six coupled wheels, 39 inches in diameter, and one Bissel truck, the cylinders being 12 inches in diameter, with a length of stroke of 20 inches, and weighing 20½ tons in working order. Of these there are on the Western system, twenty-eight; and on the Midland system, ten.

3. Engines having six coupled wheels, from 39 to 42 inches in diameter, and a four-wheeled bogie, the cylinders being 15 inches in diameter, with a length of stroke of from 20 to 22 inches; they weigh 30 tons in full working order, including 600 gallons of water in side tanks. Of these there are on the Western system, thirty engines; Midland system, thirty-six; and Eastern system, twenty-five engines.

4. Engines having four coupled wheels, 4 feet in diameter, and a four-wheeled bogie with wheels 27 inches in diameter, the cylinders varying from 13 to 15 inches in diameter, with a length of stroke of from 18 to 20 inches, weighing from 22 to 30 tons in working order. Of these there are on the Western system, thirty engines; Midland, seventeen; and on the Eastern system, eleven engines. Two, however, on the Eastern system are increased to 32 tons, by special fire-boxes for burning colonial coal.

5. Shunting engines, sixteen in number.

6. "Fairlie" engines, two in number.

The classes 1, 2, 4, 5, and 6 were ordered in the earlier stages of construction. Class 3 has been principally ordered for the later extensions.

The coaching stock consists of three hundred and ninety-nine vehicles, comprising two hundred and sixteen short carriages, one hundred and seventy-two bogie carriages, three Cleminson carriages, and eight pay- and mail-vans; some few of the bogies contain van compartments. The wheels are 33 inches in diameter, with wrought-iron naves and steel tires and axles. The coupling is of the link-and-pin pattern, the draw-bar and buffer being combined in the centre of the carriage, with safety-chain underneath.

The carriages described as "short" are 16 feet long, with an

outside width of 7 feet 3 inches, and a height of 9 feet 9 inches, from rail-level to the top of the roof at the centre, with a wheel base of 8 feet, and were those sent out for the earlier sections of the line, having been used exclusively for the first five years: but a higher rate of speed became necessary in order to satisfy public opinion, and it was therefore considered desirable to introduce the bogie system, and the later shipments have been on that principle.

There is no doubt about the bogie stock being more steady than the shorter carriages, both as regards vertical and horizontal oscillation, and its advantages in respect to stability in passing round sharp curves are very marked. This would naturally be supposed, the angle which the bogie frames make with the centre line of the carriage being increasingly great in proportion to the sharpness of the curves: thus giving a greater lateral width of base. On one occasion this was practically illustrated in a marked degree, when on a damp morning a train got beyond control on a long incline of 1 in 40; the result being that all the short vehicles were capsized at a curve of 5-chains radius, and the one bogie carriage in the train kept the rails, although the draw-bar was bent to a right angle by the derailing of the adjoining vehicle.

The wagon stock consists mostly of the short type, that is of an inside length of 14 feet, and an outside width of 7 feet 3 inches; the most generally useful wagon is a short cattle truck with gable ends, and a bar longitudinally in the centre of the wagon connecting their points, to which is attached a tarpaulin extending over the sides; thus converting it into a covered goods wagon. It may have the disadvantage at times of involving the haulage of a certain amount of dead weight, beyond the actual requirements of the goods; but the cattle traffic is so fluctuating, that some combination arrangement is necessary, and the plan of a fixed tarpaulin effects a material saving, as the friction is restricted to fixed points, which can be strengthened.

The adoption of the bogie principle has not been attended with so much advantage in the wagon- as in the coaching-stock, owing to the increased expense of haulage and repair, and from the fact that the individual wagons are often too large for traffic requirements.

Brakes.

Clarke's chain brake until within the last two years was the only continuous brake adopted; from the fact, however, of the

men engaged in its working not being always experienced, its employment was sometimes attended with jerks and breakage, and the simple vacuum brake has been accordingly introduced on the Western system, its use on the suburban line proving advantageous, as compared with the chain brake actuated by the guard from the rear of the train.

A material improvement has, however, been recently introduced in the chain brake by working it from the tender, and it is proposed to retain it, to be worked from and acting upon the rear end of the train as an emergency brake, in the event of the train parting near the engine in the ascent of long and steep inclines.

The plan of "pinning down" the brakes of goods wagons in the descent of long and steep inclines has been adopted successfully.

Speed.

The small amount of passenger traffic renders it necessary, as a rule, to run "mixed" trains, and for the sake of economy a low rate of speed was adopted, namely, 15 miles on an average per hour, including stoppages, for mixed goods and passenger trains. Where the gradients are long and steep, and the curves severe, it has been the practice to limit the speed to from 10 to 12 miles per hour, which still admits, on long lines, of the average speed being maintained without strain; but on lines where a large portion of their length consists of such gradients and curves, it is a question whether this average rate of speed is not too great for the economical working of goods traffic.

One passenger and mail train without goods is run each way per week between Port Elizabeth and Cape Town in connection with the ocean steamers. The distance, 838 miles, is covered in forty-three and a quarter hours, or at an average of 19·38 miles per hour, including stoppages, and there are suburban passenger trains which travel at a considerably greater speed.

The fastest long journey on record was that of a special train between Beaufort West and Cape Town, a distance of 339 miles in ten hours, exclusive of stoppages, or an average of nearly 34 miles an hour.

Results.

The whole of these lines, with the exception of about 70 miles on the Eastern system, which are in an advanced state of progress,

have been opened for traffic, having occupied from the time the prosecution of the earlier lines was definitely decided upon, about ten years. This is exclusive of a period of delay in their progress, averaging eighteen months on the three systems, pending Parliamentary sanction, or at the rate of about 144 miles per annum.

The total cost, including the balance for work on the 70 miles still to be completed, which is being done by contract, and the purchase of the Wellington, Wynberg, and Uitenhage lines, but without taking credit for surplus plant and materials, will be £13,671,249, or an average of £8,973 per mile. This amount includes an ample supply of rolling-stock, substantial stations, dwellings for plate-layers and traffic employees, and partly for the locomotive-department, as well as, since 1881 for the last 562 miles, interest during construction. The distribution of this total, according to the respective amounts disbursed on the three systems, gives for the Western system, £8,208 per mile; for the Midland system, £8,713 per mile; and for the Eastern system, £11,178 per mile.

The whole of the work on the Western system, with the exception of the original Wellington and Wynberg lines 64 miles in length, has been carried out departmentally, under the direction of Government engineers by piecework and small contracts, so far as practicable.

On the Midland line 232 miles were let by contract, about one-quarter of which was executed by the Government on behalf of the contractors in order to gain time, the remaining 357 miles having been executed departmentally.

The figures given above show the gross cost, including purchase of the lines bought by the Government; if, however, these be deducted with their mileage, from the gross total, the comparison is: Western system, £7,646 per mile; Midland, £8,797 per mile.

The branch of the service which would be naturally investigated with a view to testing results would be the locomotive department, as the cost in connection with the tonnage might be supposed to indicate the effect of gradients and curves; and that of repairs, the wear and tear. This, however, would be delusive, and in giving the locomotive expenditure per train-mile for the three systems, for the year 1883, as follows, Western system, 22·43*d.*, Midland, 20·02*d.*, and Eastern, 32·39*d.*, the Author may state that the cost of coal varies at the different ports to such an extent that during the year under consideration the average for the Western system was 36*s.* 8¼*d.*, Midland, 50*s.* 7*d.*, and Eastern,

69*s.* 4*d.* per ton; while as regards repairs to engines the cost per train-mile, which on the Wéstern system had previously been below that of the Midland system, was for 1883 37 per cent. above it.

The consumption of coal per train-mile was on the Western system 24·34 lbs. per mile, Midland, 18·49 lbs., and Eastern, 26·55 lbs. per mile.

Train-loads have been lighter on the Graaff Reinet line of the Midland system for want of traffic; but on the other hand there have been good loads on the Cradock line, and the train-mileage of the former is but 364,152 out of a total of 1,495,698 on the whole system.

As regards the power of engines employed, the number of miles worked by those with cylinders 15 inches in diameter and having six coupled wheels on the different systems was as follows:—Western system, 989,899 out of a total 1,584,273; Midland, 930,093 out of 1,495,698; and Eastern, 298,064 miles out of 516,437.

The maximum load assigned to the engines of Class 3, on the worst part of the different systems, as compared with a level is, for mixed trains on level parts of the line, thirty vehicles; up the Hex River mountains, Western system, ten; from Alicedale to Grahamstown, Midland system, nine; and on the severest section of the Eastern system, ten vehicles.

No very accurate conclusion can, however, be arrived at as regards the effect of curves from these assigned loads, inasmuch as on the parts of the two systems where the load of ten vehicles is given, curves of 5 chains radius occur; whereas where the smaller load of nine is assigned there is no sharper curve than 7 chains. The maximum gradient of 1 in 40 is freely adopted in all three cases, but the continuous length of 1 in 40 is greater on the Midland line than on the other two lines. The result of observation is that, where curves of sharp radius must be employed, a short rigid wheel-base saves much in haulage as well as wear and tear; but that at the same time where, within the limits adopted here, they are only occasionally introduced and not largely in immediate contiguity or at the top of a long and steep incline, they do not involve the necessity of diminishing the load, the case being met by shutting off the feed beforehand and giving another notch on the reversing lever until the curve is passed. Thus, on the Alicedale and Grahamstown line, a practically continuous length of 7 miles of gradient of 1 in 40 occurs, with curves of 7 chains radius, while on the Eastern system a continuous gradient of about 4 miles

of 1 in 40 exists with three reverse curves of 5 chains radius near its summit, and one more vehicle is assigned to the same class of engine on the Eastern system with these severe curves than on the Midland with its longer gradient but more favourable curves. A jet of water on the leading wheels of engines is found to materially diminish friction round curves.

Some careful trials were recently made on the Eastern line with a view to test the merits of various kinds of colonial coal and sea-borne Merthyr coal. These show that the consumption of the latter was at the average rate of 30·31 lbs. per mile for the double journey from East London to Queenstown and back, the average consumption on the down or inland journey being 39·04 lbs. per mile and on the return 21·58 lbs., the gross load hauled being in each case 97 tons exclusive of the engine and tender.

The consumption of fuel during these trials, having been taken by sections, admits of comparison between general ascending and descending gradients. Thus, between East London, and Blaney at 31·65 miles, the average consumption on the down or inland journey was 50·06 lbs. per mile, while on the return it was only 6·40 lbs. With a view of completing the information as to the consumption of coal on the whole journey from East London to the top of the Stormberg range, that from Queenstown to 203 miles has since been noted with a similar engine and load. The fuel in this case was colonial coal from the Stormberg, which is employed on that section, 2 tons of which, owing to the large percentage of ash, is equal to 1 ton of ocean-borne Merthyr. The consumption was at the rate of 97·36 lbs. per train-mile on the ascent, and 29·34 lbs. on the return journey, or an average for the double journey of 63·35 lbs., equal to 31·67 lbs. of ocean-borne Merthyr, being 48·68 lbs. per train-mile on the ascent and 14·67 lbs. on the return.

Maintenance of Road.

On the Graaff Reinet line of the Midland system, omitting the 13½ miles between Zwaartkops and Uitenhage, the renewals of sleepers were at the rate of from two and one-third to fifty-seven per mile per annum according to the length of time they had been in the line, namely from four to six years.

On the section above referred to, which was constructed by a private company, and opened in September 1875, the consumption was at the rate of two hundred and seventy sleepers per mile.

On the Cradock line the number varied from twenty-seven to one hundred and twenty-five per mile, according to the length of time the sleepers have been in the ground, namely from two to seven years. On the Grahamstown branch the number was from eighty-one to one hundred and twenty-two, the whole line having been opened by sections in the course of the year 1879. On the Eastern system the average renewals were twenty-four to the mile, the sleepers having been laid about three and a half years, and the ballast on this system being mostly broken stone. On the Western system, excluding the older portion between Cape Town and Wellington, they varied from thirty-one to one hundred and sixty-three. On the section between Wellington and Worcester, the longest laid, having been opened in 1876, the average was seventy-five per mile. The maximum consumption was, on the section between Worcester and Touws River, embracing the mountain section.

As regards rails, the renewals on the Graaff Reinet line, still excluding the section between Zwaartkops and Uitenhage, varied from 0·92 to 1·65 single rail per mile of line, the number on the section referred to being at the rate of twenty rails to the mile. This section was laid with 40-lb. rails, and is subject to a much larger traffic than the rest of the line.

On the Cradock line, a length of 22 miles of the first section of 42 miles which was opened in 1876, was laid with 40-lb. rails. On this whole section of 42 miles the consumption for renewals was at the rate of twenty-eight rails per mile, while on the remaining portions of the line, opened in sections from 1877 to 1881, the consumption varied from 0·4 to 1·5 rail, there being no relative proportion between consumption and length of time the section had been opened. On the Grahamstown branch the consumption was at the rate of from 1·13 to 1·47 rail per mile on the different sections.

On the Eastern system the average number of rails absorbed in renewals was 15·7 per mile for the whole system.

On the Western system, still excluding, as in the case of sleepers, the old part of the line between Cape Town and Wellington, the renewals amounted to five rails per mile for the first-laid section between Wellington and Worcester, ten rails for the next section between Worcester and Touws River, embracing the Hex River Mountains, and five rails per mile for the rest of the line to Beaufort West.

The traffic results for 1883 are given in the annexed Table:—

——	Western system.	Midland system.	Eastern system.
Total tonnage	202,922	154,170	95,878
Number of passengers . .	2,210,759	268,286	105,119
	£.	£.	£.
Earnings from all sources .	393,934	366,690	154,650
Working expenses . . .	257,679	252,795	138,975
Train-miles run . . .	1,182,482	1,015,970	405,016
	£. s. d.	£. s. d.	£. s. d.
Earnings per mile of line open	853 0 0	807 0 0	891 0 0
Earnings per train-mile .	0 6 7·95	0 7 2·62	0 7 7·64
Expenses per train-mile .	0 4 4·30	0 4 11·72	0 6 10·35
Maintenance of way and works per train-mile .	0 1 2·52	0 1 11·55	0 1 4·49
Maintenance per mile of line open	155 1 7	219 10 10	160 8 1
Locomotive department expenditure per train-mile	0 1 10·43	0 1 8·02	0 2 8·39
Net earnings per cent. . .	3 4 4½	2 13 7	0 15 7¾
Net earnings per cent. on Main line (branches excluded)	3 16 7	3 12 9	1 2 1

The Colony is at present passing through a period of depression, the gross receipts of 1882 having exceeded those of 1883, with a less mileage of open line. In the meantime the Orange and the Modder, the two principal rivers on the way to the Diamond Fields, are being bridged, in order to gain time in the future construction of the extension of the line beyond Hope Town, a distance of about 74 miles.

The Author's connection with the undertaking began with the commencement of the Wellington railway in 1858, of which he was Resident Engineer.

Since 1881 he has been Consulting Engineer in the Colony for all railways under construction, with a seat at the Board for working railways. The supreme professional control in England has devolved upon Sir Charles Hutton Gregory, K.C.M.G., Past-President Inst. C.E.

The Paper is accompanied by several maps and sections, from which Plate 11 has been engraved.

(*Paper No. 2066.*)

"Comparative Study of Various Methods of Traction applicable to Railways."

By MARCEL DEPREZ and MAURICE LEBLANC.[1]

Translated and Abstracted by Dr. PAGET HIGGS.

THIS is a somewhat exhaustive series of Papers, dealing with different methods and notable examples of traction, which are passed in review in order that the advantages of the substitution of electrical methods, as proposed by the Authors, may be judged. To give the comparison direct interest, the application to the Metropolitan Railway of Paris is more particularly studied. The subject is divided under three heads:—

1. Means of correcting defective adhesion.
2. Special study of several methods of traction.
3. Application to the Metropolitan Railway of Paris.

Under the first heading, the introductory Paper classifies:—

1. Gripping the rails.
2. Use of central rail, with artificial lateral pressure thereon.
3. Toothed or rack-rails.
4. and 5. Traction by cable.
6. Compressed or rarefied air.
7. Development of adhesion by magnetic attraction.[2]

Example of (2) is quoted as in the Mont Cenis railway, and the inconvenience of the system is stated to be a special and costly way, besides that the artificial pressure creates great passive resistance. A disadvantage of (1) is that there must not be the slightest deformation of the way. Examples of (3) are the railways on the Righi[3] and at Mount Washington (America). Besides the disadvantages mentioned, incompatibility with speed is notable. Examples of (4) are common in underground haulage; the system

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[1] The original article appeared in "La Lumière Électrique, vol. xv., pp. 4–10, 58–66, 107–115, 152–158, 199–206, 307–314, 447–456, 490–498.

[2] Minutes of Proceedings Inst. C.E., vol. xxvi., p. 313 *et seq.*

[3] *Ibid.*, vol. xxxvi., p. 103.

is limited. Continuous cable tramways, as used in several American cities, are illustrated. (5) illustrates a modification by Mr. Agudio.[1] The use of the atmospheric system (6) is well known from the examples at Dalkey, in Ireland, and at St. Germain. The pneumatic dispatch tube is a modification of this system.

The second Paper deals briefly with the immediately foregoing subject, and with (7) the Authors arriving at the conclusion that the most simple means of remedying defective adhesion consists in adopting as wheels cylindrical magnetic systems similar to the electro-magnets used by Mr. Achard in his electric brake. Even in the case where the electric current is not also employed as motive power, and where a special machine for its production is necessary, this method is preferred as simpler than a central rail, cable, or toothed rail.

This Paper also considers the following classification, as regards the study of methods of traction, by—

(1.) The ordinary steam locomotive.
(2.) Locomotives without furnaces, or "fireless" locomotives.
(3.) Compressed-air engines.
(4.) Use of electric accumulators.
(5.) Transmission of power by teledynamic cable.
(6.) Transmission of power by electricity.

The best results attainable with (1) are shortly stated. The railway from Rueil to Marly-le-Roi is given as an example of the use of (2), with illustrations.

The third Paper continues, in detail, the theory of locomotives worked from stored heated water, as also that of compressed air-motors. Details of trials of both these methods are given, and the practical difficulties recounted.

With (4) low economy is anticipated, as the result of so many transformations, as first, the production of motive power; secondly, transformation into electricity; thirdly, charging the accumulators; fourthly, discharge of accumulators; fifthly, transformation of electric energy into work. The length of time required to charge the accumulators is considered as a disadvantage compared with the rapidity of attaining working pressures with superheated water and compressed-air systems.

The teledynamic cable, as realized by Hirn[2] at Bellegarde, is considered, like all transmission by cables, to lose its advantages when curves are necessary.

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[1] Minutes of Proceedings Inst. C.E., vol. xxvi., p. 319; vol. lx., p. 380.
[2] *Ibid.*, vol. xlix., p. 23.

The fourth Paper enters upon the consideration of the direct transmission of power by electricity, and reviews what has been done since 1880.

The fifth Paper deals with the theoretical questions involved in the method of carrying the current to the motor, and with the arrangement of wires or rails therefor. The arrangement in derivation is shown to be too costly in conductor-section for large transmissions, an objection that also applies to the arrangement in derivation with opposition of connection; the arrangement in tension is that selected by the Authors, who criticise the arrangement in tension with reduced sections, as proposed by Messrs. Ayrton and Perry, and as applied in Mr. Fleeming Jenkin's telpherage.

With regard to the method of arrangement in tension (in which one conductor is continued for a certain length on, say, one set of rails, and then crossed either through the motor on the car, or through a connecting apparatus to an equal length of opposite conductor or rail), there may be the objection raised that there should be normally a car or vehicle in each section of cross-overs, and that if this is not always realized, special connecting apparatus is required. But this inconvenience may be converted into a great advantage by introducing a block system similar to that proposed by Messrs. Ayrton and Perry. The system proposed by the Authors, although described in detail, does not appear to have received practical confirmation, and in a railway they deem it preferable to employ an arrangement in derivation, because of the presence of the rails that may be used as conductors. But they would never propose to employ one rail as outgoing conductor and the other as return, because the way must then be insulated specially, and could not be traversed by the ordinary traffic of other companies, or having solid wheels. The leading conductor is therefore an aerial line, and, as designed by the Authors, consists of a brass tube 22 millimetres in diameter and 1 millimetre thick, opened at its lower part to 7 or 8 millimetres, parallel to its axis. In this tube is a small cylindrical chariot, also of brass, of smaller diameter than that of the tube. This carries two small vertical lugs, passing through the opening in the tube, and these lugs support an axial system, bearing a grooved wheel, pressed against the outer and under side of the tube by spiral springs. This arrangement gave excellent practical results on the tramway service at the Exhibition (Paris) of 1881. It is superior to that of two telegraph wires bearing a small four-wheeled carrier, because of the difficulty of obtaining equality of tension on the

two wires, and consequent liability to the derailment of the carrier.

The Authors also point out that there must always be an advantage in using large motor-machines instead of numerous small ones, and in the sixth article pass to the consideration of the electric locomotive.

In the trials in the workshops of the Northern Railway at Grenoble, a machine-test realizing the condition required of an electric locomotive, that of developing great power with small weight, was constructed with two rings, but the inductors acted only as two electro-magnets. The weight was, of

	Kilograms.
Iron in each ring	3
Copper „ „	3
Iron „ electro-magnet	18
Copper „ „	18
Of each armature	10
Total useful weight	124

The total resistance of the system was 0·12 ohm, and at a linear velocity of 15 millimetres a second, 150 amperes at 60 volts were produced with an expenditure of 12 HP. With a larger machine 25 metres velocity may be easily attained, and if it be admitted that the power of a machine increases as its weight 20 HP. might be obtained for a useful weight of 124 kilograms. A machine of 500 HP. would thus weigh 3,100 kilograms, without counting accessories, and would require 75 kilograms of iron, and as much copper, on each of its rings, which would be about 1 metre in diameter. The angular velocity would be reduced to one-half by gearing, with suitable provision against sudden shock. Although sufficient at high velocities, the adhesion of this machine would not fulfil all purposes, and a toothed rail is proposed for difficult parts of the way. This type of machine is analogous to those to be used in the transport of power between Creil and Paris, and will be described at a subsequent date in detail.

It would be very advantageous to suppress the gearing, but this would need that the wheels and rings should have the same angular velocity. The Authors have endeavoured, therefore, to find a form for the inductors which admits of increasing the diameter of the armature (*induit*) without making the machine cumbrous. They have designed the following type:—It consists of an iron ring of large diameter, covered with a series of circular (section) coils. The end wire of each coil is connected with the

end wire of the following coil, and the two communicate with one of the contacts of an ordinary collector. The wire-covered ring rests on a mandrel of wood, which is supported by an internal wheel. The inductor of this machine is constructed of two empty disks of iron. These disks are of width equal to the thickness of the ring as covered with wire. They carry, at certain distances, angle jutting pieces of iron that embrace the ring; there are an even number of these pieces. There are also an even number (or pairs) of brushes. The brushes of even numbers are in connection with one of the terminals of the machine, the others with a second terminal. When the current enters, there is thus determined in the ring a series of consequent points or magnetic poles that tend to approach the jutting pieces of iron embracing the ring. Mechanical means of reversing the direction of travel of the car are necessary with this machine, and are described as designed. The converse of this machine, or that in which the inductor revolves whilst the armature is fixed, is also outlined.

Two solutions are proposed for the reduction of the number of brushes. One is by connecting the commutator-contacts of similar potential. Or each pair of brushes may turn on a special collector, and if the contacts of the collectors corresponding to the same section of the ring are connected, and the collectors turned through a suitable angle, only one pair of brushes will be required. But these solutions have the defect of dividing the total number of bobbins carried by the ring into as many groups as there are poles, and all these groups being connected in quantity, such machines are unsuitable to develop high tension. This is avoided by the following arrangement:—Suppose four poles, and that the ring has twelve sections. Designate the first six of the latter by A, B, C, D, E, F; the others by A^1, B^1, C^1, D^1, E^1, F^1. And let *a*, *b*, *c*, &c., a^1, b^1, c^1; &c., represent the contact pieces, to the number of twelve, of the collector; *a* and a^1, *b* and b^1, and so on, are connected electrically. The contact pieces, *a*, *b*, *c*, &c., are connected to the sections A, B, C, &c., by the entering wires, and a^1, b^1, c^1, &c., to the outgoing wires of A^1, B^1, C^1, &c. The outgoing wire of F^1 communicates directly with the entering wire of section A. The outgoing wire of A^1 is connected to the entering wire of B, that of B^1 to C, and so on to F^1 with A. The outgoing wire of A is connected to the entering wire of A^1, of B to B^1, and so on. If the two brushes are set at an angle of 90° with each other, on, say, the contact pieces *b* and *c*, each half of the bifurcated entering current will successively traverse six sections, and the problem is solved particularly. The general solution is the

following:—Suppose $2n$ poles; instead of two groups of sections, there will be n groups.

$$\begin{array}{llll} A_1\ B_1\ C_1, & \text{\&c. to} & F_1, \\ A_2\ B_2\ C_2 & ,, & F_2, \\ A_n\ B_n\ C_n & ,, & F_n. \end{array}$$

In this case the sections $A_1\ A_2\ A_3 \ldots A_n$, $B_1\ B_2\ B_3 \ldots B_n \ldots F_1\ F_2 \ldots F_n$ are mounted in tension, since there are connected the outgoing wire of A_n to the entering wire of B_1, the outgoing wire of B_n to the entering wire of $C_1 \ldots F_n$ to A_1. The collector will contain n groups of contact pieces. The contact pieces of groups $a_1\ b_1\ c_1\ d_1\ e_1\ f_1$ will be in connection with the entering wires of sections $A_1\ B_1\ C_1$, &c. But the contact pieces $a_1\ a_2\ a_3 \ldots a_n$, $b_1\ b_2\ b_3 \ldots b_n$, $f_1\ f_2\ f_3 \ldots f_n$ will be connected by insulated conductors.

The machine described has the following relative dimensions and elements. It has six poles; the distance of two consecutive poles, measured on the mean circumference of the ring, is equal to three times the diameter of the section of the ring. The thickness of the layers of wire wound on the ring is equal to a quarter of the same diameter; the distance of the ring covered with wire to the external disks is equal to the radius of the section of ring; the pole-pieces have a thickness or width equal to quarter the distance of two consecutive poles; the thickness of the exterior disks is equal to half the thickness of the pole-pieces.

The weight of a machine of this kind, of which the mean circumference will be 1 metre in diameter, will be—

	Kilograms.
Iron ring	370
Conductor	430
Pole-pieces and disks	1,000
Or total useful weight	1,800

The Authors calculate the power of such a machine, wound with wire of 1 millimetre diameter, to be, with a tangential velocity of 25 metres per second,

	HP.
For 1 ampere	8
„ 2 „	33
„ 3 „	75
„ 4 „	132
„ 5 „	207
„ 6 „	298

The ratio of the motive power available at the driving-wheels to the electric energy absorbed by the machine will be more than

76 per cent.; if the efficiency of the regenerative machine is the same, the result will be 62 per cent.

The Authors state that as to the electromotive force the generating machine may develop, this may attain 12,000 volts, and that the trials now in preparation show that it is permissible to go as far as this.

The third part of the series of Papers contained in the seventh and eighth articles deals with the special application to the proposed Metropolitan Railway of Paris, and is thereby limited in its interest. In conclusion, the Authors describe their particular objects in view at some length, and these may be resolved into the establishment of an electric railway under the best conditions of efficiency, and in which, instead of separately empowered vehicles, a locomotive is caused to propel a train. There may be thirty locomotives on a line of 40 kilometres, and the locomotive may be of 15 to 20 tons (metric) weight. The other objects have been referred to in this abstract.

(*Paper No. 2071.*)

"The Public Works of the Orange Free State, S. Africa."

By Gustave Hallé, Assoc. M. Inst. C.E., Commissioner of Public Works, Orange Free State.

The Orange Free State is one of the youngest independent countries in the world. Its government is barely thirty years old, and it has only within the last few years commenced public works of importance; the Department of Public Works having been instituted, and the Author placed at the head of it in the summer of 1881.

The Orange Free State is a tract of land some 70,000 square miles in extent, to the north of the Cape Colony and Basuto Land. It was colonized in 1840 by Boer settlers from the Cape, was taken over by the British Government in 1848, and surrendered again to the Boers in 1854. It is an undulating table land, from 4,500 to 6,000 feet above sea-level. It is almost entirely a grazing country; there is little cultivation, except for home use and to supply the villages of the State; and there is little or no timber beyond spare tracts of thorn bush. It is almost surrounded by the Orange and Vaal rivers, and there are several fairly sized rivers traversing it in various directions; these vary from about 50 feet in width by 3 feet in depth during dry seasons, to from 500 to 2,000 feet in width by 30 to 60 feet in depth during floods. They rise rapidly, and are very dangerous on such occasions. There are also numerous other smaller streams, dry for the greater part of their length in winter, and as much as 100 feet wide by 25 feet deep during rains. These often rise and run down again in the course of a few hours.

The annual rainfall, as tested at five or six stations, has varied in the last five years from 16 inches to 31 inches; the average is probably from 20 to 25 inches. The heaviest fall per month in this period has been 10 inches; the least, under 1 inch.

The population of the country is 61,000 whites, and 72,500 blacks. There are twenty districts, each with a Landdrost or resident magistrate, and about twenty-two towns. The only industry is the diamond-mining, at Jagersfontein, Moffyfontein,

&c., employing, according to the varying prosperity of the pursuit, from 1,500 to 3,000 people.

Attempts have been made to open up the coal-fields of the country, which have been pronounced by experts to contain 1,250,000,000 tons, valued at £300,000,000 sterling. The present difficulties of transport have, however, hitherto prevented the delivery at the diamond fields, at Kimberley or Jagersfontein, at a price to compete with imported coal and wood. There are known to exist also immense beds of iron ore, estimated at 263,000,000 tons, worth over £200,000,000 sterling; but no attempt has as yet been made to develop them.

According to the census of 1880, the Free State possessed 135,000 horses and mules; 60,000 oxen; 6,000,000 sheep and goats; 2,000 ostriches; and 13,000 pigs.

Until lately the only public works and buildings undertaken by Government were the care of the main postal roads and the providing of the magistrates' offices, prisons, schools, and other buildings required for the administration of Government. These were severally kept in order and built under supervision of unpaid local committees.

The success of the Kimberley diamond mines in 1870 gave a considerable impetus to the Free State by establishing a large market just outside the borders; and as a consequence caused a demand for better means of intercommunication.

Railway bridges and telegraphs were discussed for several sessions, and at last in 1878 telegraphic communication was voted between Cape Colony and Bloemfontein, the seat of Government. A line similar to the colonial lines, constructed largely with olive-wood poles, was completed in 1879, at a cost of £88 per mile. A further line from Bloemfontein to Natal was voted in 1879, and completed in 1880, which, as well as the former, was constructed by the Government engineers, Messrs. T. G. and B. H. Howard. Heavy floods interfered with the work, but the total price for the 218 miles, including freestone offices, and all expenses, came to £128 per mile. These lines have iron poles. Further lines to the Colony and to Kimberley have been completed in 1881 and 1882, on the same system, and at about the same cost.

The whole of the works were carried out by native labour, under the above two engineers. Transport occasionally rose to 20*s.* 6*d.* per 100 lbs., and water had sometimes to be fetched as far as 14 miles for camp use. For some 50 miles on one section all rocks had to be blasted with dynamite and powder to the depth

of 3 feet 6 inches to 4 feet 6 inches. In June 1882, 306 miles of internal lines, and a connecting line to the Transvaal, were commenced under contract, Mr. B. H. Howard surveying and inspecting the construction. The contract price was £98 15*s.*, and the total cost, including offices, &c., about £120 per mile. Transport during this period was much lower. The wire used on these lines is Johnson & Nephew's No. 6 B.W.G. charcoal telegraph wire milled; the instruments are Siemens' self-recording Morse; the batteries, Siemens' and Halske's, and Daniell's; the furniture of the offices is solid mahogany. There are very few angles on the line, the longest straight run being 69¾ miles. The General Manager is Mr. A. C. Howard. The rate per message is 1*s.* per ten words, and 6*d.* for every additional five. The annual expenses are £8,900; the returns about £8,400. The prospects are not good, owing to the central position of the Free State and the low rates agreed on by the South African States and Colonies.

During the construction of the above telegraph lines, bridges and railways were also discussed, and a few preliminary surveys of sites and lines taken. A succession of droughts, and the commencement of the decline of the diamond-mines, have induced the Volksraad to postpone the commencement of railways; but in 1881 a first series of five bridges was voted, and the Department of Public Works and Buildings was founded, the construction of the telegraph lines, bridges, public buildings, &c., being placed under it.

It may be interesting to mention what the duties of the Author, as head of this department, have included.

The works under his charge are divided into remunerative and unremunerative. Under the latter head came, in the year 1883, the building of five magistrates' offices, eleven prisons, nine telegraph offices, eight schools, three teachers' and eight goalers' houses, three toll houses, one lunatic asylum, one barracks, and sixteen more or less important repairs. These sixty works are scattered over a country the size of France. They were designed at the head office, the staff of which consists of the Author and one assistant, put to tender, and carried out under the supervision of unpaid local building committees, assisted by visits of inspection by the Author. Travelling in this country is by means of two-wheeled covered carts, drawn by two horses; and the inspection of bridges and buildings involved on the Author in the above year two hundred and forty days' travelling, covering on an average 40 miles a day.

The remunerative works have consisted of the telegraph lines mentioned above, and the five bridges voted in 1881. A loan of £200,000 was voted in 1883 to defray the cost of these works, and the first £100,000 successfully floated.

The bridges have comprised three steel bridges, and two stone ones. The first steel bridge was of four spans of 150 feet; the second, two spans of 100 feet; and the third, one span of 100 feet, and a culvert of 15 feet. The stone bridges were of one span of 75 feet and three spans of 33 feet 4 inches respectively. The whole series will have cost between £60,000 and £65,000.

The leading points to consider in the designs were: the entire absence of timber, except ordinary deals as imported for house buildings; the cost of transport from the coast, all goods being brought most of the way by open wagon, at rates from 10*s.* per 100 lbs. to £1 10*s.*; the scarcity of good white labour, or of any sort of black labour; and the uncertainty of the extent of the floods, these having been steadily on the increase since the settling of the country, owing probably to the making of roads, grass burnings, &c. The sandiness and looseness of the banks, and their constant widening.

A large quantity of drift wood being washed down at each flood, it seemed desirable to have the spans over the main rivers not less than 100 feet. In the Caledon River Bridge, a design of four spans of 150 feet of steel was estimated at about £15,000 for masonry and earthworks; and £15,000 for the superstructure. The cost of transport then being high, viz.: 17*s.* 6*d.* per 100 lbs., the Author elected to construct the bridge of steel at a strain for tension and compression of 6½ tons per square inch, giving a dead weight of 79 tons per span, as against 99 tons if of wrought iron, strained in compression to 4½ tons, and in tension to 5 tons per square inch. The saving in transport alone at these rates amounted to nearly £2,000.

The girders are parabolic bowstring, with pin joints, the lower bolts being 5 inches in diameter, the upper 3 inches. The girders are 21 feet 5 inches high in the centre, 16 feet apart, with the cross girders hung below on straps and gussets. The rolling weight per span was taken at 157 tons, the bridge being required for a railway, if subsequently desired. No riveting was needed on the site, all connections being by bolts. The strains on the boom and tie vary from 207 to 238 tons. The cross girders are hung under the main girders to allow at once a maximum waterway, with a minimum height of roadway above the banks, the latest floods having reached bank level. No masonry abutments were built,

the flood of 1874 having widened the river by 30 feet, and the appearance of the banks making it quite possible that a similar widening might occur with a similar flood. The abutments were therefore built as piers, carried, of course, down to the solid, and the end slopes of the embankments were protected by a thick shield of dry stoning, easily repaired, if partially damaged. Should the banks be again widened, a stout, new, extra span would be added. The cost of the abutments, if made of masonry, to stand such a violence of water would have been double.

This bridge was erected on a platform supported by fourteen steel wire ropes, 3 inches in circumference. The platform was designed for a dip of 5 feet in the centre of the wires, and proportionate trestles were placed under each upright and properly braced along and across. All the woodwork was made of 9 inches by 3 inches deals. An initial camber of 2 feet was given, and the wires were tightened, as they stretched under the increasing weight by 2-inch straining screws secured behind the pier on the one side. The other ends of the wires were carried over the other pier to the foot of the pier beyond, and there secured. The total weight of the platform was 14 tons, and it proved amply strong enough to support the weight of the span during erection; it was very stiff against both vertical and lateral vibration, easily put up, and easily removed. It is plain how important a saving can be achieved by this system of erection. The total metal work in wires and straining screws, &c., does not exceed 3 tons for a platform of this size, and ordinary deals, sufficient for the trestles can be obtained anywhere.

The main point to be observed is the relieving the heads of the piers, between which the platform hangs, of any but a vertical strain, by providing for the free passing of all the wires over the pier-head to the foot of the west pier on the one side, and by well securing the support of the straining screws to the land, or to the completed spans on the other. On this occasion, only half of the wires were passed over to the farther pier; the remainder were secured to the pier-head, a course which appeared to give an undesirable oblique strain to the pier-top.

The formula $S = \frac{C\,L}{8\,V}$ will give the section of wires required, and the Author is confident from this experiment, that, by observing the above precautions, a similar staging carefully worked out to meet circumstances will be found sufficient and economical. It renders the erector independent of the state of the river, and avoids the undue strains occasioned by the methods of

protrusion, or drawing over. The total cost of this bridge was £34,000.

The smaller steel bridges are on a similar system, each span being 100 feet. No difficulty has been met with in erecting them on ordinary trestles, the height above the river-bed having been under 30 feet in each case.

The total saving by the use of steel, and consequent lessening of weight, has exceeded the extra cost of home manufacture in steel by about £1,500 on the three bridges, the saving having been on the items of transport, freight, dues, and erection. This was in spite of the fact that transport had fallen from 17*s.* 6*d.* to 8*s.* 9*d.* per 100 lbs.

The last two bridges have been built of stone, with a very satisfactory result.

Owing probably to the dulness of trade in Europe, and the deceptive attractiveness of the gold and diamond fields, plenty of skilled tradesmen of every branch are to be obtained by advertisement for work in any part of South Africa. The natives, especially the Zulus, and certain of the Cape blacks, make excellent quarry men and labourers of all kinds. The only apparent limit to the building of bridges here in stone is the cost. The cost of masonry of this kind averages, all told, £5 to £6 per cubic yard, and there is danger of floods interfering with the scaffolding. In view, however, of the advantage of retaining the money in the country, instead of sending it to Europe for a metal superstructure, the preference will in future be given to stone where possible. Capital building stone is obtainable almost throughout the State.

Several flying surveys for projected railways have been taken from the capital in different directions; these show that the construction of railways over the undulating flats of this country would be extremely simple. One large item of expense, that of sleepers, might be greatly reduced by the use of steel bowl-sleepers, instead of wooden ones. The chief point for consideration is the proper allowance of culvert room for the vast volumes of water that rush down every incline in the summer thunderstorms and floods.

Every year, by the formation of new roads, sheepwalks, &c., this difficulty is increased, both for railway and bridge work, by the more and more rapid draining off of the rainfall from the surface into the rivers.

As regards irrigation-works, the matter has been mooted in the Volksraad, and the Author has had to submit various reports on steps feasible. The country possesses many facilities for the formation of large reservoirs. Ancient lake-basins abound, which

might easily be restored by damming up again the narrow outlets by which the waters have escaped. The smaller streams, which are numerous, are suitable for fixed and movable weirs, and the declivity of the rivers is so great that it should be easy to lead out water by pipes and furrows. The difficulty lies mainly herein, that the farms are so large, 10,000 to 12,000 acres, that any individual works of the description could at most benefit a small group of individuals. Government is thus precluded from the task, and it is beyond the means of most of the farmers. The only available scheme appears to be the adoption of the Cape Irrigation Loans Act, which provides for government loans for irrigation-works to single farmers, or groups of farmers, on very easy terms of repayment.

Meanwhile the advance of the colonial railways to the borders has mostly destroyed the markets of the Free State, and a succession of droughts has so impoverished the whole country that the greatest distress is prevalent. The existing public works, the telegraphs and bridges, yield so far insufficient returns, and projected new ones have been postponed.

It is, however, admitted on all hands that a serious effort must be made to meet what threatens to become an exceptionally grave crisis. The ever-recurring scarcity of water must be remedied, and railways are becoming an absolute necessity. It is beginning to be hoped that the pressure of the times will overcome the proverbial reluctance of the Boer to tax himself, especially now that his ingenuity has been almost exhausted in devising means of extracting the last obtainable tax and license from the professional and mercantile classes. It is also hoped that, in spite of the depression, the present bridges will yield at least enough to prove the success of the present loan of £100,000, and to establish the utility of the system.

The steel bridges over the Caledon and Liebenberg rivers were manufactured by Messrs. Brettell and Co. of Worcester; that over the Eland river by Messrs. Woodall of Dudley; all under the supervision of Mr. G. Knowles, M. Inst. C.E., Consulting Engineer for the Orange Free State. The stone bridges were built by Messrs. Jones, Moir, and Cobban of Kimberley, South Africa. Messrs. A. White and E. Evans were the Resident Engineers. The masonry of the steel bridges was built by Messrs. Goodman and J. Holmes of the Orange Free State, and the erection of the steel bridges was undertaken by Messrs. Scrimgeour Brothers of Port Elizabeth, South Africa.

(*Paper No. 2077.*)

"The Purification of Water by means of Iron on the large scale."

By William Anderson, M. Inst. C.E.

During the session of 1882-83, in a Paper on "The Antwerp Water Works,"[1] the Author had the honour of bringing under the notice of the Institution an adaptation of Professor Bischof's method of purifying water on a large scale by filtering it through a mixture of spongy iron and gravel. The operation of the process, as far as the effect upon the water was concerned, left nothing to be desired; uninterrupted work for nearly four years did not appear to have materially enfeebled the power of the filtering medium, nor to have sensibly diminished its quantity. Two defects, however, very soon became apparent. First, the filters, dealing with the exceptionally impure waters of the Nethe, proved incompetent to purify more than half the quantity of water expected; and, secondly, the upper layer of the mixture of gravel and spongy iron gradually hardened into a crust, and became clogged with slimy matter to such an extent as to render it necessary periodically to uncover the purifying medium, loosen its upper surface, and wash away the deposits which had accumulated. But the very circumstance that these operations became necessary, affords the strongest evidence of the potent action of iron. The purifying beds were, in the first instance, covered with a layer 2 feet deep of fine filter sand; the water was allowed to subside for at least twelve hours before it was admitted to them, and therefore must have reached the iron in as pure a state as ordinary subsidence and sand filtration could bring it to; and yet, the moment the surface of the iron mixture was reached, action took place so energetically, that not only was the mixture itself affected in the manner described, but the influence of the iron seemed to extend even upwards, as was evidenced by the discoloration of the sand for 2 or 3 inches above the iron. These facts, the Author considers, are a conclusive answer to those who, in the discussion on the Paper referred to, alleged that simple

[1] Minutes of Proceedings Inst. C.E. vol. lxxii. p. 24.

sand-filtration would attain the same results as those which had been reached by the iron method. The deposit which caused so much trouble was a mixture of salts of lime and magnesia, derived from the softening of the water, and of organic impurities partly rendered insoluble by the action of the iron, and partly curdled up into a condition too gross to pass through the filter bed. It is hardly necessary to remark that no deposit of impurities is ever found between the sand and gravel of ordinary filter-beds, hence the impurities deposited at Antwerp must have been separated by the action of the iron. The steady increase in the demand for water rendered it evident that, at no distant date, the filters would prove incompetent to supply the engines, therefore the Author, in conjunction with Mr. G. H. Ogston, Assoc. Inst. C.E., set to work to devise means by which the extraordinary powers of iron might be taken advantage of at a less sacrifice of capital and space than had hitherto been found practicable. The great difficulty lay in the rooted idea that, in practice, a contact of at least three-quarters of an hour was necessary to produce the required effect. The late Professor Way and Mr. Ogston had, indeed, shown that with very finely-divided iron, unmixed with gravel, a much shorter contact would suffice; but it was known also that a filter constructed of iron only in such a condition would very soon become clogged, so that no advantage would ultimately be gained. Mr. Ogston in conjunction with the Author made numerous experiments with various forms of apparatus, devised so as to ensure a rapid passage of water through a mass of material kept open by means of agitation, but the success was not commensurate with the cost of working, so that plan after plan had to be abandoned. It was at last determined to try a method which had, at the very first, been suggested to the Author by Sir Frederick Abel, C.B., F.R.S., Hon. M. Inst. C.E., who in Medlock's time had already had considerable experience in the use of iron for purifying purposes, namely, that of abandoning all attempts at filtration, or the passage of water through large masses of iron, in favour of simple agitation of a comparatively small quantity of iron with the water to be treated. A wrought-iron cylinder 4 feet 6 inches in diameter by 6 feet long was accordingly arranged so as to revolve on hollow trunnions, and was fitted up internally with six shelves or ledges, whose office would be to scoop up the charge of iron placed inside, and shower it down continuously amidst the water flowing slowly through. The inlets and outlets were at first 2 inches in diameter, the intention being to purify at the rate of 12 gallons per minute, which would give the supposed necessary

contact of water with the iron of forty-five minutes. The cylinder was charged with 9 cwt. of iron, and set revolving at the rate of one-third turn per minute. The trial showed that vastly too much metal was being taken up by the water; the rate of flow was therefore increased to 30 gallons per minute, when 1·2 grain of iron per gallon was dissolved; and then to 60 gallons, when 0·9 grain was taken up, a quantity still far in excess of what experience at Antwerp showed to be sufficient, namely 0·1 grain per gallon. These experiments were so encouraging, that new trunnions with 4-inch pipes were fitted to the cylinder, and the apparatus was sent to Antwerp, where it was finally put to regular work on the 13th of March, 1884, at the rate of 166 gallons per minute, giving a contact of three and a half minutes only, which proved to be amply sufficient to purify the water. The quantity of spongy iron used during a run in which 6,854,400 gallons were passed through was 0·176 grain per gallon, including coke and other impurities, which form about 30 per cent. of the material, so that in reality about 0·1 grain of pure iron per gallon only was taken up by the water.

The great advantage of using iron in the manner described arises from the circumstance, that the surfaces of the material are always kept clean and in an active condition by rubbing against each other and against the inner surfaces of the cylinder which contains them, as well as by continually falling through the mass of water. It is found that iron in almost any divided form is suitable for the process. The most active agents are cast-iron borings and turnings, on account, no doubt, of the way in which each particle is cracked and fissured; next probably, comes so-called spongy iron; then cast-iron granulated by being poured into water; and lastly, wrought-iron and steel turnings.

The unexpected discovery that the time of contact between the iron and the water could, in practice, be reduced to about one-twelfth of what had always been held necessary, completely changed the aspect of affairs. The Author was able to convince the Directors of the Antwerp Water Works Company, by means of the steady and perfect action of the experimental revolver for many months, that the proper course to pursue would be to adopt the system for the whole of the supply, and convert the spongy-iron filters into sand beds. This recommendation was accordingly adopted, and the arrangement indicated on Plate 12 was immediately carried out.

The apparatus consists of three revolving purifiers, together capable of dealing with 1,500 gallons per minute (2,160,000

gallons per day), a small wall engine and line of shafting for driving them, a tank fitted with a fine screen for separating coarse impurities, and a purifying house 26 feet by 31 feet by 11 feet 6 inches high, added on to the screw-pump annexe of the main engine-house.

Each purifier consists of a wrought-iron cylinder, 5 feet in diameter by 15 feet maximum length, supported longitudinally on hollow trunnions 10 inches in internal diameter, fitted with stuffing boxes, through which the inlet and outlet pipes pass. The journals formed upon the trunnions, which are 15½ inches in diameter by 5 inches wide, rest in cast-iron blocks fitted into standards, which are secured to the thick concrete floor which covers the whole area of the house; the blocks are each capable of vertical adjustment by means of a wedge and screw, which enables wear to be readily taken up, a precaution rendered necessary to avoid cross-strains on the inlet and outlet pipes.

For scooping up the iron and showering it down through the water, the inside of the cylinder is fitted up with five curved ledges 8 inches deep, and one ledge 6 inches deep, the latter formed of twenty blades 6 inches long, each attached to a $\frac{7}{8}$-inch shank, which passes through the cylinder, and is secured to it by a nut. The object of this arrangement is to give the means, by placing the blades askew, of throwing the iron back toward the inlet end of the cylinder, if the current of water passing along should tend to make it travel towards the outlet.

The inlet pipe, where it opens into the cylinder, is covered by a disk of plate-iron, 2 feet 8 inches in diameter, fitted within $\frac{5}{8}$-inch of the spherical end, so that the entering water is compelled to spread out radially in all directions into a disk $\frac{5}{8}$-inch thick. The outlet-pipe was, in the experimental revolver, protected by a screen of finely-perforated zinc, for the purpose of preventing the smaller particles of iron being washed out, but it was found to choke so rapidly with moss and other floating impurities, that some different plan had to be devised. The Author ascertained, by experiment, that a velocity of 4 inches per second was incompetent to move any but the finest iron in a vertical tube; he accordingly expanded the outlet-pipe inside the cylinder into an inverted bell-mouth, of such diameter that the current upwards would not exceed 4 inches a second. The iron falling over this contrivance slips down its external surface, and is not carried up again by the slow upward current of water. A good deal of trouble was expected from the probability of the iron travelling with the water, but experience has shown that this tendency either does not exist at all, or is of

a very feeble nature. The mean velocity of flow through the cylinder is only a little over $\frac{3}{4}$-inch per second, but this motion is probably very irregular, made up of endless eddies, which effectually prevent the onward motion of the iron. The experimental revolver worked for months without any shifting being observed, but the larger ones above described have shown a slight tendency in the direction expected.

The 10-inch outlet-pipe communicates by means of a bend with an upright pipe of 12-inches diameter, which rises through the bottom of a tank, to which it serves also as a partial support; the lower end rests on the concrete floor of the house, and forms a pocket or trap, fitted with a handhole and door, from which any fine iron which may be carried over is readily removed. In the centre of the cylinder is an ordinary manhole, fitted with a cover, in which is a 3-inch brass screw-plug, through which periodical additions to the charge of iron can readily be made.

An air-cock is provided for the purpose of letting out the air when starting, and of getting rid, periodically, of the gases which, with some waters, collect during the running of the apparatus. These gases are so poor in oxygen that they instantly extinguish a lighted taper. The three revolvers are placed side by side, and connected, on the inlet side, by 10-inch branches, fitted with sluice-cocks to the 20-inch delivery main from the screw-pumps. The outlet-pipes all open into a wrought-iron tank, 15 feet long, 3 feet 6 inches wide, and 3 feet deep, fitted with an inclined screen, covered with galvanized wire-netting, four meshes to the inch. A shallow trough is formed at the upper end of the screen, for the purpose of receiving and draining the solid matter scraped off from time to time. The object of the screen is to catch the large quantity of moss and other impurities which, especially in summer, form in the inlet pipes to the screw-pumps, and, constantly becoming detached, find their way to the filter beds. It is noteworthy that no such growths take place after the water has been purified. To shut off any of the revolvers from the tank, a lid, fitted with an india-rubber ring, is simply laid over the end of the delivery pipe.

The driving-gear consists of an annular spur-ring, secured round one end of each cylinder. Each ring is actuated by a train of gearing working in a self-contained frame, secured to the floor of the house, and driven by a $2\frac{1}{2}$-inch belt from a lay shaft, coupled direct to the crank-shaft of a wall-engine, having a cylinder $6\frac{1}{4}$ inches in diameter, 9 inches length of stroke, fixed in the screw-pump house. The total weight of each revolver, filled with water

and with its charge of 22 cwt. of iron, is 14 tons 6 cwt., and the power necessary to drive it at the rate of one-third of a revolution per minute is 0·4 HP.

The total capacity of the three revolvers is 15,000,000 gallons per week.

The cost of the establishment in this country, including the house, would be £2,300, while the cost of working, after allowing 5 per cent. deterioration of the building, and 10 per cent. for that of the machinery, together with 5 per cent. interest on the outlay, would be 9*s.* 9*d.* per million gallons; the cost in wages and materials alone amounts to 2*s.* 6*d.* per million. The total quantity of iron in use is less than 3½ tons. Had the original filter beds been extended so as to do the same work, the weight of iron in them would have been 1,800 tons. The iron dissolved per week in full work will be about 2 cwt.

The revolvers were started on the 12th of March, 1885, and have continued working steadily ever since; the water supplied to the town is reported to be exceptionally bright and clear, so that no doubt need exist as to the success of the new method of purification. The distribution of the iron throughout the length of the cylinders remains singularly even, not only with respect to quantity, but also with reference to the proportions of fine to coarse particles. The Author's colleague, Mr. G. H. Ogston, will deal with the chemical aspect of the process.

The Paper is accompanied by several drawings, from which Plate 12 has been prepared.

(*Paper No. 2077a.*)

"The Purification of Water by Metallic Iron in Mr. Anderson's Revolving Purifiers."

By George Henry Ogston, F.C.S., F.I.C., Assoc. Inst. C.E.

It is not the object of the present Paper to enter more fully than is absolutely necessary into the chemical reactions involved in the purification of waters by metallic iron, but rather to record the results actually obtained with a considerable number of specimens of water, of various degrees of impurity, on exposing them for a time to the action of iron in a moderately fine state of division.

The Author's reasons for desiring to confine himself within these limits, are, first, considerations of space, and then, that the changes which take place under these circumstances have not been thoroughly investigated. It has long been known that important effects were produced, in depriving impure water of its dissolved organic matters, by permitting it to remain in contact with clean iron surfaces for a time. Some thirty years ago, Medlock, in a patent for water-purification, described a mode of employing iron-turnings for the purpose, which up to a certain point was no doubt successful. It was not, however, largely adopted, probably on account of the impossibility of keeping the surface of the iron free from oxidation, by which its efficiency was soon impaired, and improvements were not introduced in the methods, probably because less attention was paid to the question of pure water then than is now the case. It does not seem to have been seriously pursued so far as the Author is aware, until Professor Bischof introduced and patented the use for this purpose of a form of iron now called spongy iron, iron, that is to say, which has undergone incipient fusion only, after its reduction from the ore. The iron so prepared was mixed by Professor Bischof with fine gravel to keep the individual masses apart, and was used as a filter-bed of about 3 feet in thickness. This form of filter has been successfully employed in dealing with the water of the River Nethe, which now supplies the town of Antwerp; and was continued in use there until the new revolving purifier was introduced a short time ago, on increased quantities of water being required by the town. The difficulty experienced in mere filtration through a bed of iron, is in a great measure a financial one. A

large space is occupied by the filter-beds, and a great quantity has to be employed of the rather costly material.

A full description of the works at Antwerp has been laid before the Institution by Mr. W. Anderson, M. Inst. C.E.,[1] from which it will be gathered that the great original cost of laying out the large filter-beds and stocking them with iron, interposed serious obstacles to the introduction of that system in many situations, and has led to a search for a mode of utilizing the purifying power of metallic iron, in which the necessary apparatus would be less costly, occupy less space, and employ less material. Successful experiments in this direction led to the construction of the revolving apparatus invented by Mr. Anderson, which quite fulfils all the required conditions.

About three years ago the late Professor Way and the Author, whilst experimenting upon the subject, separately made the observation, that with clean and finely-divided iron the destruction of the organic matter in water, as indicated by the reduction of the so-called albumenoid ammonia, was much more rapid than had hitherto been supposed; and a great number of experiments showed that the extreme effect must have been produced almost instantaneously, since less than half a minute's agitation brought down the albumenoid ammonia to its lowest point. The Author may at once say, that it appears never to be absolutely removed; but there is good reason for believing, as the result of experiments to be described further on, that the actively injurious forms of organic matter are destroyed. These observations led to a variety of experiments on the best mode of using pure iron.

Simple filtration through a sufficient quantity was of course amply effective for a time; but, as had been shown, the practical adoption of that system was out of the question, on account of the liability to oxidation and cementation together of the metallic particles remaining without movement. Several forms of moving apparatus were suggested, but the apparatus patented by Mr. Anderson, which embodies also an idea of Sir Frederick Abel, Hon. M. Inst. C.E., overcomes all difficulty in dealing with iron as a purifier.

The main objects in view in the employment of this revolving apparatus were to keep the iron in motion, and to be assured that the whole quantity of water passing through should be in contact with the metal for a sensible time; and further, whatever iron is brought into solution should, with the mechanical impurities, be

[1] Minutes of Proceedings Inst. C.E. vol. lxxii. p. 24.

continually carried away by the stream, to be afterwards separated by filtration through sand filters in the form of ferric oxide, to which condition it is quickly brought by exposure to the air. Mr. Anderson has fully described the apparatus in his Paper; and it only remains to say, therefore, that the perpetual friction of the particles of iron over one another, whilst the cylinder revolves, and their contact with the shelves, which, during work, lift the iron from the bottom and allow it to fall in a shower through the water, keep the surfaces of the separate grains always bright and active. The form in which iron is most effective, and, for several reasons, appears best adapted for use in this apparatus, is the borings of cast iron. In action the particles break up into small fairly-smooth plates, with few irregularities; so that by the rubbing of one grain against another the whole surface is kept clean and bright. Wrought-iron turnings do not expose so much surface in relation to their weight, and much of that surface escapes any rubbing action from the form of the coils. Granulated iron, formed by pouring molten iron into water, as suggested by Sir Frederick Abel, answers well, and, when properly prepared, exposes a fairly large surface. The material called spongy iron does not answer so well on account of the roughness of the individual masses. By friction only the prominences are brightened and a good deal of the surface becomes ineffective from the retention in the interstices of the suspended impurities of the water. On the whole, therefore, cast-iron borings are to be preferred.

The experiments now to be mentioned have all been made in the Author's laboratory, with a model apparatus constructed by Mr. Anderson, and used in every way as the large forms (Plate 12) would be used; with the same rate of flow, and the same quantity of iron in relation to the water to be purified, differing only, in that the experiments were necessarily interrupted from day to day, instead of being continuous, as in practical work they would be.

The capacity of the model revolver is 3½ lbs., and this quantity of water passes through in from three to five minutes.

It has not up to this time been possible to examine a large number of waters, but those that have been dealt with present a considerable variety in composition, and are probably fairly representative of waters commonly met with. The first obvious effect of the iron upon an impure water is to deprive it of any colour it may have. A minute quantity of the iron is immediately dissolved, probably as ferrous carbonate, and almost immediately thrown down as ferrous oxide. After a short exposure this becomes ferric oxide, which is deposited and separated with great

ease by filtration through a very shallow layer of sand. The Author has found 4 inches of sand generally sufficient to produce a perfectly bright sample at a rapid rate of filtration; the time required for subsidence and oxidation before filtration is from five to six hours. The effect of this treatment upon the waters that have been examined is, to deprive them entirely, as seen through a tube 2 feet long, of the colour due to the presence of dissolved organic matter; and this removal of colour is accompanied by the breaking up of certain nitrogenous compounds, as shown in the analytical results, and by a great reduction in amount of the albumenoid ammonia. The Author has chosen this mode of expressing results because the method of analysis by which they are obtained permits the examination of a large number of samples, and indicates, in his opinion, the degree of impurity in ordinary waters very completely. It has been said that the action of the iron is almost instantaneous; and in some cases it is astonishingly rapid, whilst with highly polluted waters a distinctly longer time is necessary for the full effect to be produced, so that from eight to ten minutes may be required in extreme cases, in others a third of that time being sufficient. It is proved that, whilst much of the organic matter is affected by the iron, a certain proportion of it either resists its influence altogether, or undergoes only partial change; this proportion is generally represented by from one-third to one-half of the quantity that would have appeared under the head of "Albumenoid Ammonia," but the waters are in all cases deprived of the colour that impure water possesses, and are reduced to the pale-green tint of pure water.

The following Table shows the amount of albumenoid ammonia, in a million parts, in several waters that have been analysed, and includes samples varying greatly in composition, and in the original quantity of organic nitrogen.

	Before Purification in Revolver.	After Purification in Revolver.
Water from Zurich	0·020	0·010
" Ostend	0·140	0·080
" Laeken	0·185	0·060
" Thames	0·150	0·060
" Malines	0·260	0·060
" Antwerp	0·200	0·080
" Northwich . . .	0·110	0·040
" Itchen	0·080	0·040
" New River . . .	0·030	0·015
" Hertford sewage . .	0·330	0·080

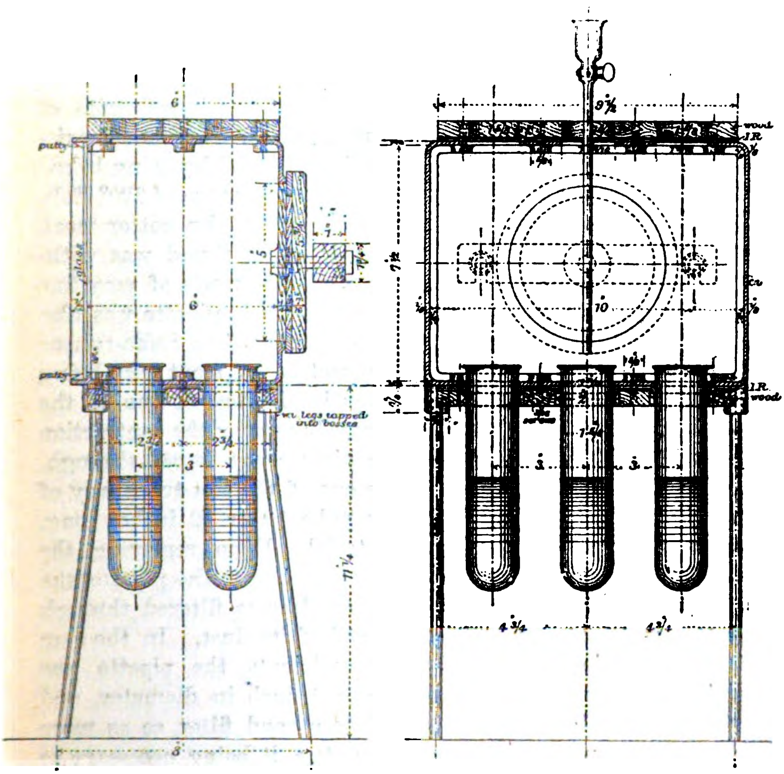
Why a certain proportion of these nitrogenous compounds resists the action of the iron, whilst the larger portion is broken

up, is not clear, but the Author hopes at a future time to be able to acquire some information upon these points. It is plain that there are two classes of compounds, one of which only gives up its nitrogen readily, either as free nitrogen, or in the form of nitric acid, or of ammonia, and it would be of the greatest importance to show, if possible, that the more stable forms are less to be dreaded in a potable water than those which are more easily decomposed. To fix upon any particular quantity of organic matter as it is now determined, or to describe the special form, that can be positively said to be injurious to health, is beyond the powers of the chemist; but if a water contains distinct evidence of animal pollution, it can be said there is danger that the source whence the pollution is derived may supply the poisonous germs of disease, whenever sickness occurs within the drainage area of that district. The time indeed seems to be near when, by the aid of the physiologist and the microscopist, it may be possible to say what special danger is to be feared from a polluted water. In the case of one of the samples on the list, viz., the Zurich water, this is said to have been done. It contains, as will be seen, less albumenoid ammonia than any other sample, and less indeed than it is usual to find in the best waters; but the report of a German physiologist shows that typhoid fever had occurred in the district supplied with water from this source; and that he had found in it a form of bacterium which, when multiplied by pure cultivation, induced characteristic symptoms in the lower animals. He was thus able to recognize as dangerous a water, which by analysis appeared to be exceptionally pure. With the knowledge of what had been done by Dr. Frankland, Professor Bischof, and the late Mr. Hatton in regard to the proof of the destructive effect of spongy iron upon the bacteria existing in water, the Author instituted some experiments upon the waters which had been treated in the revolving purifier, to ascertain if these microscopic organisms were affected by so short an exposure to the action of iron as was sufficient to effect the changes already described. The test was to be the relative power of the water, before and after treatment, to set up putrefactive fermentation in a properly prepared meat-extract. Whatever views may be held as to the germ theory of the propagation of disease, it is certain that decomposition of animal matter quickly occurs on its exposure at common temperatures to moisture and ordinary air, from which the usual dust has not been separated; but that, if the air has been deprived of dust and the organisms inseparable from it, by filtration or other effectual means, organic substances may be

freely exposed to it without undergoing change. So with water, if it be filtered through a medium sufficiently fine in texture to retain the microbes—biscuit porcelain, for instance—or be sterilized by repeated boiling, it will not induce decomposition in meat-extracts rendered specially sensitive even, and may be considered to be preservative in its effect. On the other hand, as all natural waters contain a greater or less number of the organisms that cause, or at all events accompany, fermentation or putrefactive change, either derived from the air, or more directly from drainage sources, it will be of great importance if it can be shown that they can be got rid of, or rendered innocuous, by an easily applied purifying process. Although the microbes that induce decomposition in the test meat-extracts are not necessarily, or even probably, identical with those that occasion actual disease, it is not unfair to suppose that the agency that destroys or renders inert one class of bacteria, will be fatal to all classes of them; and that if a polluted water, after being submitted to this system of purification, is incapable of inducing putrefaction, all organisms originally present have been destroyed, and that the germs of special disease acquired from drainage sources have therefore been got rid of.

The experiments, made by the Author upon waters after being in contact with metallic iron, lead him strongly to the belief that this treatment completely destroys the microbes. In most of the experiments the water, after passing through the revolver, was incapable of setting up fermentation in either hay infusion or meat-extract, although occasional failures in the experiments occurred, especially at first. These were mostly to be traced to the difficulties of excluding access of air during the operations, and to defects in the apparatus employed for the demonstration. Several forms of apparatus were used, but the two ultimately preferred by the Author may be described. The first of these, shown in the annexed figure, p. 291, provided by Mr. Anderson, resembled almost exactly the sterilizing boxes employed by Professor Tyndall, and consisted of a box, in the first place made of teak wood, and later on of thin cast iron in one casting, raised on four legs about 12 inches from the table. The front was glazed, and made perfectly air-tight with cement; in the back there was an aperture 4½ inches in diameter, closed by a disk capable of being pressed by a cross-piece and screws tightly against an india-rubber washer, this aperture being necessary for the introduction of the test-tubes containing the meat-extract, &c. The top and bottom of the box were pierced with six holes 1½ inch in diameter, and covered with sheets of vulcanized india-rubber ⅛ inch thick;

this was firmly held by covers of wood ½ inch thick, screwed to the top and bottom of the box, and having in them holes corresponding with those in the box itself. From the bottom sheet of rubber, disks were cut out less than an inch in diameter, so that when test-tubes of rather more than an inch across were forced through the apertures thus made, they were secured



DETAILS OF STERILIZED CHAMBER.

Scale ¼.

perfectly against access of air by the contraction of the india-rubber. Before being introduced, the tubes were filled with meat-extract or hay infusion to about one-half of their capacity. The box was now closed by screwing on the cover at the back, and the solution in each of the tubes boiled for six or seven minutes gently. It was then allowed to rest for three days. When it was known by experience that the contained air would have deposited all its

dust, with whatever germs or spores might be associated with it, and would be therefore incapable of inducing fermentation of any kind, the solutions were again boiled very gently, to destroy whatever might have fallen directly into the tubes, and the arrangement was complete. Eight or ten of these boxes so prepared were available at any time for the various trials. The Author should have said that at one upper corner of the box a small hole was made, into which was fitted a quill glass tube, bent two or three times, and stopped at the extremity with cotton-wool. This allowed the escape or entrance of air during change of temperature and barometric pressure without the introduction of dust. The water to be tested was received direct from the exit-tube of the model revolver in a test-tube sterilized by being baked in an oven, reserved for the purpose, at a temperature of 320° Fahrenheit for five hours. The tube was stopped by cotton-wool, treated in the same way, and the water to be tested was withdrawn, by forcing through the wool a pipette made of very fine tubing drawn to a point (at the upper end this pipette was also stopped with sterilizing wool), and by means of an india-rubber tube, sucking up about 1 cubic centimetre. A stout pin being now pushed through the india-rubber in the top of one of the boxes, the hole so made closing up immediately by the contraction of the india-rubber, the point of the pipette was forced through, and, when sufficiently far, directed to one of the test-tubes, any of them being able to be reached by a tube 10 or 12 inches long, owing to the flexibility of the material. Upon removing the pressure of the fingers upon the tubing attached to the pipette, the water passes in, and the air taking its place is filtered through the cotton-wool stopper, and so deprived of its dust. In the case of a considerable number of the experiments, the pipette was expanded in its upper part into a tube 1 inch in diameter, and 5 inches long, which was converted into a sand filter, so as more nearly to represent what occurs in practice, it being necessary to filter water after the iron treatment, to separate the deposited oxide of iron, &c. After filling in the sand to form the filter, the whole was sterilized in the usual way by baking for five hours. Upon the introduction into the apparatus of the water to be tested by the mode described, means were taken to maintain the temperature at about 80° Fahrenheit, and almost invariably at the end of two days a corresponding quantity of the water which had not been purified, had rendered its tube of meat-extract cloudy from the swarms of bacteria produced, whilst, if the experiment was successful, no cloudiness either in the tubes to which no

addition had been made, or in those to which purified water had been added, was perceived.

A second, and more simple, arrangement has been employed with success in many instances. It consists only of a flat glass plate 4 inches square, and a hemispherical cover accurately ground on its edges, 3½ inches in diameter. The plate is supported upon a large sheet of thick glass, capable of holding six or eight of the smaller ones, and by screws adjustable so as to be made exactly level. This precaution is necessary, because the Author prefers to use a meat-extract, which when cold is still fluid, so that any water added to it may diffuse itself throughout the whole, without its being necessary to expose it to air long enough to mix them together by stirring, and if the arrangement is kept quite level, 3 to 4 cubic centimetres of solution may be placed in the centre of the plate, without danger of its running out to the edges. The plates and covers, being sterilized, were placed upon the larger sheet to cool; 4 cubic centimetres of the meat-extract were withdrawn from the stock preserved in a flask, by pushing a pipette through the cotton-wool stopper, and deposited in the centre of the plate, the cover being momentarily removed for the purpose. By another pipette, ½ cubic centimetre of the water to be tested was added to the extract with the same precautions, and immediately covered up. Besides the purified water, there was always prepared at the same time for comparison, the water in its original condition, and some of the meat-extract without addition. The meat-extract employed by the Author, made according to the directions of Dr. Koch, was of beef, and neutralized, to which was added the necessary quantity of gelatine. It was, after boiling, filtered, so as to be absolutely bright, and the strength was arranged that at a temperature of 60° Fahrenheit it was just fluid.

The waters upon which most of the experiments have been made, to which the Author desires to draw attention, have been, water from the Thames, as being easily obtainable, and water from Laeken (Belgium), an impure water, of which the Author had a quantity at his disposal. In the case of the Thames water, five experiments out of seven in which it was passed through the revolver were successful, the water being completely sterilized, whilst two failed. In the Laeken water, which is taken from a stream supplying the lake in the park of His Majesty the King of the Belgians, three experiments succeeded, and one experiment failed. With the Zurich water, remarkable as being almost free from organic matter, and supposed to have occasioned much disease, the only experiment made showed that in its original

condition it rapidly developed bacteria in the meat-extract; but that it was completely sterilized after purification. With water from Northwich, in two experiments, the sterilizing effect was produced, and in one case it failed. Throughout the trials, in about four cases out of five, the mode of treating the waters that has been described has completely sterilized them; it must be understood that in every case the water not so treated was active in determining the decomposition of the meat-extracts under similar circumstances, and that comparative trials were always made with the samples in the two conditions side by side. In spite of all precaution, it is very difficult to exclude the momentary access of air during the various transferences of the water and meat-extract from the revolver to the testing-glasses, and the Author attributes most of the failures to this cause. It seems that if in the great majority of cases the organisms are destroyed, the effectiveness of the agent is established, since it is not at all likely to be capricious in its action. Considering these facts, and considering also the great reduction effected in organic nitrogen, and the removal of colour from impure waters, there appears to be reason for the belief that an economical and efficient method of water purification has been found in this mode of treatment by metallic iron; indeed, it would seem that impure waters purified by means of iron will prove safer for dietetic purposes than even good deep well or spring water, because after treatment the water can be preserved from contamination by means of covered reservoirs, or in the mains and pipes, whereas wells and springs, as numerous cases prove, may become dangerously contaminated.

The only specimen of true sewage the Author has been able at present to deal with in this way is that from Hertford, taken from the Manifold ditch below the town. The result of experiments with this liquid, so far as they were carried out, was very satisfactory. The albumenoid ammonia was always reduced to 0·08 in a million parts, and of the two experiments that were able to be made with it, after purification, one was completely successful in destroying all organisms. The second experiment, which exhausted the supply of sewage, failed from an accident to the apparatus. In the case of a water so highly polluted as this, no doubt a comparatively prolonged contact with the iron is necessary, and with this particular sample fifteen minutes were allowed.

The Paper is accompanied by a drawing from which the figure in the text has been prepared.

(*Paper No. 2078.*)

"The Effect of the Drought of 1884 upon the Pollution of the River Thames below London."

By Robert William Peregrine Birch, M. Inst. C.E.

It will be remembered that a Paper by the Author has been read at the Institution of Civil Engineers,[1] the object of which was to describe by what has now become known as the "chlorine method," the mutual action of the upland-water and sea-water in the estuary of the Thames, having reference specially to their effect in carrying away the dissolved sewage of London.

The analyses and calculations then described, which were made for the Corporation of London in 1882, had reference to two conditions of the river only, namely, a period of about average upland flow and one of heavy flood.

When, therefore, during the summer drought of 1884, the foul condition of the river became notorious, it occurred to the Author that it would be interesting to learn exactly to what extent the sea-water was acting in mitigation of the nuisance at a time when the diluting effect of the fresh-water was reduced to a minimum; and in August, having ascertained that the Thames Conservators had been gauging the river, he decided to make the necessary observations.

Samples of water, taken on the 30th of August and the 8th of September at the following places simultaneously, were analysed by Mr. Gerrard Ansdell, F.C.S., at the Royal Institution Laboratory, with the results stated in the Appendix, Table I.

The water in the mouth of the river was found even more salt than the standard adopted for absolute sea-water in 1882, it was therefore necessary to adopt a proportionately higher standard for the present calculations.

By the courtesy of Mr. C. J. More, M. Inst. C.E., and Mr. Henry Law, M. Inst. C.E., the Author was enabled to obtain the gaugings of the flow of the Thames, and also such tide-gauge diagrams as enabled him to arrive, with the help of cross-sections, at the cubic contents of the river at the times when the samples were taken.

By the expression "sewage" the Author means any liquid

[1] Minutes of Proceedings Inst. C.E., vol. lxxviii., p. 212.

which has passed through a sewer before entering the river. He has not dealt with the much vexed question of the destruction of the organic impurities by the dissolved oxygen contained in the water, upon the extent of which so much difference of opinion prevails, as a discussion of this question would be foreign to the object of the present Paper.

It has been assumed that absolute sea-water contained 2,045 grains of chlorine per 100,000 grains of water as against 1,961 in 1882; that the upland-water contained 1·7 grain of chlorine per 100,000 grains as in 1882; and that 26,000,000 cubic feet of sewage a day entered the river with 10 grains of chlorine per 100,000.

By consideration of the relative quantities of upland-water and sewage forming the fresh-water flow of the river, the amount of chlorine due to these two factors, irrespective of the ocean, was arrived at. The amount was found to vary from 4·6 grains at Barking to 1·7 grain per 100,000 at Teddington, the limit of the tidal range.

As in the calculations referring to 1882, the proportion of the channel occupied by upland-water and sewage was found as follows:

$$p = \frac{2045 - c}{2045 - b};$$

Where p = proportion of fresh-water in the sample;
b = chlorine in 100,000 parts of mixture of upland-water and sewage; and
c = chlorine in 100,000 parts found in the sample.

Foi Barking the formula would stand thus:—

$$p = \frac{2045 - c}{2045 - 4 \cdot 6}.$$

From the gaugings of the Thames during the summer of 1884, the Author was enabled to calculate how many days' upland-flow of the river the columns arrived at by means of the above equation represented.

The average daily flows contributing to the fresh-water columns shown on Plate 13, were for the 30th of August, 1884, 82,424,345 cubic feet, and for the 8th of September, 79,867,067 cubic feet; against, on the 22nd of September 1882, 176,528,502 cubic feet, and on the 14th, 172,364,082 cubic feet, corresponding tides in that year. This shows a reduction in each case of more than 50 per cent.

It was found that all the fresh-water and sewage which had entered the river between Teddington and Southend since the 25th of June was still there on the 8th of September, and that all the fresh-water and sewage that had entered since the 16th of June was still there on the 30th of August.

Of these quantities the flow of forty-five days, namely from the 16th of June to the 31st of July, was found below Barking on the 30th of August, and the flow of forty-five days, from the 25th of June to the 8th of August, was found below Barking on the 8th of September. The sewage which was off Southend on the 30th of August was therefore forty-five days old, and that which was off Southend on the 8th of September was also forty-five days old. This also shows that the fresh-water which, mixed with this sewage, was off Southend on the 30th of August, had passed over Teddington Weir seventy-five days before, and that which was off Southend on the 8th of September seventy-six days before.

It is proved by these observations that in August and September, 1884, owing to the prolonged drought there was less fresh-water in the river and more salt-water than in September, 1882, and the fresh-water was travelling seawards, with its impurities, at a much slower rate.

But it must be understood that drought has another important effect besides that of reducing the quantity of upland-water available for dilution. For, proportionate to the progress of the upland-water seaward is also the circulation of sea-water which is always taking place in the estuary; so that less sea-water comes into the river in a given time during drought, when the upland-water is at its minimum, than in wet seasons, when there is a smaller volume of sea-water in the river. In other words, notwithstanding that in time of drought there is a larger volume of sea-water in the river, its circulation or renewal is so slow that its effect as a diluent is greatly reduced. This will be seen on comparing the figures taken from the diagrams given in Table II., it being borne in mind, as before stated, that the circulation or renewal of the sea-water in the estuary is proportionate to the progress of the upland-water seaward.

From these figures it will be seen that the circulation, or renewal of the sea-water was nearly three times as rapid in November, 1882, when the river was in high flood, as in August and September, 1884, a time of unusually prolonged drought.

The Paper is accompanied by a diagram from which Plate 13 has been engraved.

[APPENDIX.

APPENDIX.

TABLE I.—CHLORINE in 100,000 PARTS.

—	At Time of High Water at Southend.		At Time of Low Water at Southend.	
	Aug. 30th. Neap tide.	Sept. 8th. Spring tide.	Aug. 30th. Neap tide.	Sept. 8th. Spring tide.
Southend Pier	2,010	2,034	1,933	1,909
Chapman Lighthouse	1,945	1,983	1,809	1,769
Mucking Lighthouse	1,761	1,808	1,552	1,561
Gravesend	1,578	1,709	1,389	1,386
Grays	1,461	1,484	1,322	1,243
Greenhithe	1,380	1,430	1,191	1,135
Purfleet	1,334	1,410	1,035	1,020
Erith	1,210	1,255	964	955
Crossness	1,095	1,223	851	720
N. Woolwich	922	942	638	541
Deptford	530	598	283	267
St. Paul's Pier	206	220	78	99
Putney	2·5	10·25	2·6	3·1
Kew	1·7	1·9	1·7	1·9
Teddington	1·7	1·7	1·7	1·7

TABLE II.—OPERATION of DROUGHT in REDUCING the DILUTING EFFECT of the OCEAN on the POLLUTION of the THAMES (000,000 omitted).[1]

Date and Description.		Mean Total Contents of River in Cubic Feet.	Mean Volume of Sea-Water in Cubic Feet.	Mean Volume of Upland-Water and Sewage in Cubic Feet.	Average Daily Volume of Upland-Water and Sewage contributing to values in previous Column in Cubic Feet.	Days occupied by the Upland-Water and Sewage in traversing the distance between Barking & Southend.	Average Daily Quantity of Clean Sea-Water entering the River from the Ocean in Cubic Feet.	Average Quantity of Water, including Sewage, reaching the River from all sources Daily in Cubic Feet.
1882. Sept. 14th. Spring tide. Sept. 22nd. Neap tide	Mean of	26,771	20,624	6,147	189	32½	634	823
Nov. 30th. Intermediate tide		26,325	15,740	10,585	884	12	1,312	2,196
1884. Aug. 30th. Neap tide. Sept. 8th. Spring tide.	Mean of	27,157	22,775	4,382	97	45	506	603

[1] The figures refer to that part of the river between Barking and Southend.

(*Paper No. 2080.*)

"Description of Steel Permanent Way, as used on the London and North-Western Railway."

By Francis William Webb, M. Inst. C.E.

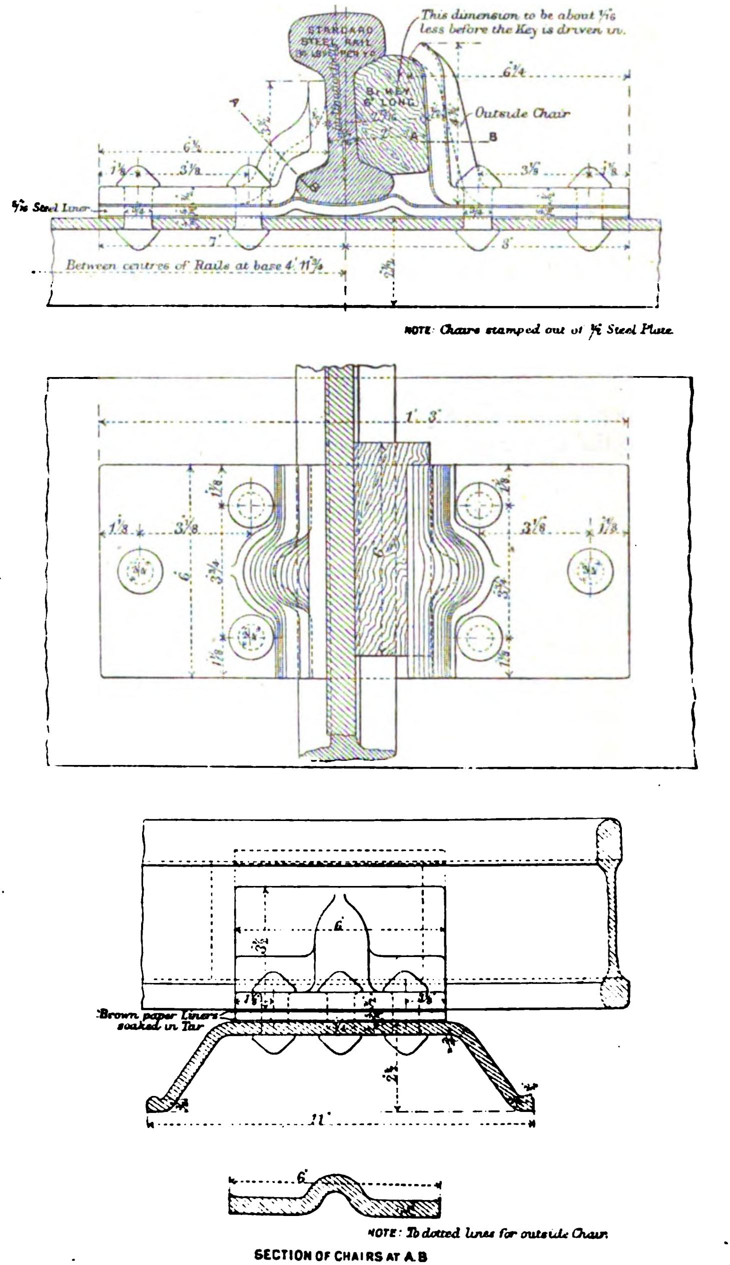
The accompanying figures show a form of steel or iron permanent way which was designed by the Author as a substitute for the present system of wood sleeper and cast-iron chairs.

The sleepers are by preference of the ordinary trough section, and the chairs are riveted to them.

The chairs, which form the chief feature of the design, are made from the cross-ends of steel rails. These are first rolled into flat bars, and then cut and stamped into shape with a bulge in the middle of their width, so as to give strength to the jaws, and also to form a recess into which the wooden key may expand, and so prevent it from working out. It will be noticed that each chair is made of two-angle brackets, and a packing-piece, which serves to keep the rail from injuring the sleeper. Another feature is the placing between the sleeper and the chair pieces of paper pasteboard or canvas dipped in tar or asphalt, to keep out moisture and to prevent sliding or working between the chair and the packing, and between the packing and the sleeper.

The system is one that seems to offer the advantages of economy and simplicity of manufacture. In the case of the sleepers, if they are to be generally adopted, to enable them to be produced at the lowest cost, it is advisable as far as possible to introduce one standard form of sleeper, and one standard method of punching. In this way companies, wishing to adopt steel sleepers, might go into the market for them, as they would for a piece of timber for the same purpose, and not have to ask the manufacturers to alter their rolls, or their machinery for punching the holes, for every small order. The matter would be still further simplified if the bottom table of the rail were also made a standard, leaving the engineers to adapt the top table of the rail (which should be of the bull-head section) to their own requirements.

The London and North-Western Railway Company began to experiment with this form of permanent way in May, 1880; there are now on various portions of the line 32,174 sleepers at work;


This dimension to be about 1/16 less before the Key is driven in.
STANDARD STEEL RAIL
OAK KEY 6" LONG
Outside Chair
5/16 Steel Liner
Between centres of Rails at base 4' 11 3/4
NOTE: Chairs stamped out of 1/2 Steel Plate.
Brown paper Liners soaked in Tar
NOTE: To dotted lines for outside Chair.
SECTION OF CHAIRS AT A.B

the first have been down nearly five years, and are showing very well at the present time. One of the advantages of the system is, that it is applicable to the present standard rails and keys without alteration, so that a length of the ordinary wood sleeper road can be taken out and the steel sleepers substituted without any difficulty. With regard to first cost, it compares very favourably with the present system; but if the manufacture is undertaken on a large scale, or under the conditions which have been pointed out, the cost would be still further reduced.

The weight of one sleeper and chairs complete, as used on the London and North-Western Railway is 184 lbs., the weight of the sleeper, 9 feet long, being 136 lbs., and of two chairs and liners, 48 lbs.

The Paper is accompanied by a photograph and a Diagram, from which the illustrations have been prepared.

(*Students' Paper No. 190.*)

"On the Blasting and Removal of Rock under Water, and the Construction of a Deep Water Quay, at Blyth Harbour."

By WILLIAM KIDD, Stud. Inst. C.E.

AT the time that most of the coal shipped from the Northumberland coal-field was carried in sailing vessels, the port of Blyth was a very flourishing one. Large numbers of sailing vessels were owned in, and traded constantly with it. Gradually, however, as the steamship took the place of the sailing vessel the trade fell away, as no efforts were made to encourage steamers to frequent the port. In the year 1880 the coal shipments had fallen to a low figure, and it became an absolute necessity to provide accommodation for a steam trade before any improvement could be looked for. Accordingly, arrangements were entered into between the harbour authorities and the North-Eastern Railway Company, whereby the former undertook to provide extensive deep-water berths, and the latter to erect two first-class high-level staiths adapted for the rapid shipment of coal, the whole being designed for steamers up to 2,000 tons carrying capacity. The works were commenced in May 1881, and were completed in the spring of 1884; since then the coal shipments have been very materially increased.

The site determined upon for the new berths was on the south side of the River Blyth, about a mile from the harbour entrance (Plate 14, Fig. 1). The bottom of the river at this place was formed by a large patch of rock which had long formed a serious obstruction to dredging operations; it was necessary to remove this in order to provide the required depth. A new deep-water quay adapted to the altered circumstances had also to be constructed.

I.—REMOVAL OF ROCK.

A plan of the rock to be removed is shown in Plate 14, Fig. 2. A careful survey of the reef was made by the Author when the work was commenced. In shape it resembled roughly the segment of a circle, the chord being formed by the old quay wall. The

length of the portion removed was 700 feet, the greatest width being 139 feet 6 inches, decreasing to 8 feet at the lower and to 88 feet 6 inches at the upper end. The surface was dry at low-water of spring tides for a width of 85 feet from the old quay. The whole area removed was 7,803 square yards, and the area within the 70-feet line was 5,333 square yards. A depth of 15 feet below low-water level of ordinary spring tides was provided. The range of an ordinary spring tide was 14 feet 6 inches, so that the depth provided at high water of ordinary spring tides was 29 feet 6 inches. The width of the new berths was 70 feet from the line of new quay, which is sufficient to enable two large steamers to lie alongside each other. Outside this width the bottom rose at a slope of 10 to 1 to the surface of the rock. The depth removed across the centre portion averaged 14 feet 5 inches over the 70-feet width, decreasing to nothing at the outer edge. The greatest depth removed was 16 feet. A section showing the rock removed is represented in Plate 14, Fig. 3. The surface was overlaid by a thin coating of mud and clay; it was not found necessary to remove this previous to blasting.

The material consisted of yellow sandstone rock, shale, and clay, lying in horizontal beds; there was also a considerable proportion of very hard quartzite in the form of large boulders and irregular beds. A section of the strata is shown in Plate 14, Fig. 4. It was of a very irregular character, and the clay layers were the worst feature, as they rendered effective blasting difficult.

The means employed for removal were: first, boring and blasting, and second, dredging.

The boring was executed by hand-labour, the men working from the decks of rafts. The rafts were 25 feet long by 13 feet wide, and were constructed of yellow pine logs, decked over with planking. The bore-holes were $2\frac{7}{8}$ inches in diameter. The drills had chisel-pointed bits $2\frac{3}{4}$ inches broad; the shanks were in lengths of round iron $1\frac{1}{4}$ inch in diameter, the lengths being connected as required by screw spigot and socket-joints; a cross-head could be attached at any required height. Boring tubes 3 inches in diameter were firmly driven into surface of the ground after the raft was moored in position, and the drills worked within them. The tubes prevented sand getting into the bore-holes, and enabled the cartridges to be rammed home from the raft without the aid of a driver. Four men were required at each drill. The average speed of boring was about 3 lineal feet per hour, and the cost of labour was 1*s.* per lineal foot. The operations were at first conducted by "tide-work" during the low-water period, but it was found inconvenient

and expensive; "day-work" was then resorted to with advantage no trouble being experienced from the greater depth at high water, as had been anticipated.

The trial borings indicated that the material was of so soft a character that it was believed the whole depth of the rock could be removed in one lift; it was also expected that gunpowder would be sufficiently powerful to blast it effectively. Owing to the small power of the dredger employed, these measures were found insufficient, and it was accordingly determined to remove it in two portions, first, roughly, to about 9 feet, and second, to the finished depth of 15 feet below low-water of ordinary spring tides; and also to substitute a powerful explosive for gunpowder.

The bore-holes were laid off in sections 9 feet apart longitudinally and transversely, with an additional hole in the centre of each of the squares thus formed, which formed diagonal squares of 6 feet 3 inches. This arrangement is shown in Plate 14, Fig. 5. The upper series of holes were bored to 10 feet 10 inches below low water, and the holes in the second or lower portion were carried 6 inches below the intended level of the new bottom, or 15 feet 6 inches below low water. The lower holes were of an average depth of 6 feet 6 inches, and with these shorter holes the rock was much better broken and was dredged most freely.

Various explosives were adopted for blasting. Gunpowder was first employed, but it was ineffective, and the ground on which it was used had afterwards to be re-blasted by means of dynamite. The other explosives were Nobel's No. 1 dynamite, and gelatine; tonite and lithofracteur were experimented with, but proved inferior to the last named. The blasting gelatine was found to be the most suitable, as the dredger always got the rock most freely where the ground had been blasted by its agency. This explosive is described as consisting of ninety-three parts of purified nitro-glycerine combined with seven parts of nitro-cotton; it is an explosive in all respects well adapted for sub-aqueous blasting. The prices of explosives on the works were, per lb.:—gunpowder, 4½*d.*, dynamite, 1*s.* 7½*d.*, and gelatine, 2*s.*; fuze cost 1*s.* per 24 feet coil.

The blasting-charges were contained in water-tight tin cases 2 inches in diameter; they were closed at the top with wood plugs 2 inches deep. Bickford's double-coated gutta-percha fuze, and Nobel's detonators were used, and there were few misfires except in frosty weather, when the dynamite was liable to burn. No tamping material was employed, the water being quite sufficient. A section of a cartridge is shown in Plate 14, Fig. 6.

After blasting the material was removed by dredging. The

greater portion of the material was loaded into hopper barges, towed to sea and deposited about 3 miles from the site of the works.

The dredger employed was that already in the possession of the harbour authorities; and, although not sufficiently powerful, was the only one available. It was a single-ladder, central-well machine, having a low-pressure condensing engine of 25 HP., the cylinder being 26 inches in diameter, and the length of stroke 36 inches. The boiler was 20 feet long, by 6 feet in diameter, and the usual working-pressure was 10 lbs. per square inch. The hull was of wood, and was 100 feet long by 25 feet broad by 10 feet deep; the draught of water was 6 feet. The bucket-ladder was 60 feet long and was provided with thirty-two buckets and "claws"; the greatest depth to which the buckets reached was 23 feet. The engine was connected to the top tumbler by spur-wheel gearing, each wheel being provided with a friction-nave; it is remarkable that not a tooth of this gearing gave way in the course of the operations. In soft sand and mud this machine has, under favourable circumstances, raised 90 tons per hour, taken over twelve hours' work. The speed at which the rock was dredged was about 6 tons per hour taken over a fortnight's work, and allowing for stoppages of the engine while shifting the vessel, &c., or only one-fifteenth of the speed at which the soft material was removed. The whole of the bucket gear was subject to very heavy wear and tear, and was eventually all made of steel. The buckets were each of 2·8 cubic feet capacity, the weight being 5 cwt.; the pitch of chain was 2 feet. The crew of the dredger consisted of six hands. The hoppers were each of 120 tons capacity, and were three in number.

A "Priestman" grab or bucket was occasionally employed, and it proved very effective in the removal of large loose pieces of rock, many lumps of from 1 ton to 2 tons weight being lifted. It proved, however, to be of little use for the removal of rock in bulk, unless thoroughly blasted.

The dredging was carried out in sections across the river. The rock was got most readily when it was dredged immediately after blasting. It was generally well broken as it came up in the buckets; but occasionally large pieces of 2 or 3 tons weight were met with which the dredger could not lift; these were removed by a floating steam-crane aided by a diver, or by the "Priestman" grab. Dredging was carried on both day and night, two crews working alternately in twelve-hour shifts.

After the dredger had gone over all the ground, it was found

that small ridges and patches about 12 inches high occurred irregularly over the bottom. These were removed uniformly to the required depth by a diver, who was generally able to reduce them by means of a pick or bar; and when this was impracticable by means of a short borehole and a small charge of dynamite.

On the completion of the deepening operations the bottom was carefully sounded, and examined by a diver; and before vessels were admitted into the new berths the river bed was in a perfectly safe condition. Except at low water of extraordinary spring tides, there is never less than 15 feet depth of water in the berths, and at neap tides there is about 19 feet, so that large steamers when loaded are well water-borne at all states of the tide.

The quantity of rock removed was 24,500 cubic yards; and a large quantity of mud and sand, which was brought down the river by scour, was also removed. Upwards of four thousand five hundred $2\frac{7}{8}$-inch holes were fired; and the total quantity of all kinds of explosives used was 20,915 lbs., or 0·853 lb. per cubic yard of rock removed. After deducting gunpowder, 11,820 lbs. of explosives, principally nitro-glycerine compounds, were used, or 0·482 lb. per cubic yard. The cost of explosives, including fuze and cartridge-cases, amounted to 1*s.* 4*d.* per cubic yard in the first, and 1*s.* 2*d.* per cubic yard in the last case. The expense of boring, including all charges, was 1*s.* 9*d.* per cubic yard, so that the cost of boring and blasting was 3*s.* 1*d.* per cubic yard. The dredging cost 3*s.* per cubic yard, which was inclusive of all repairs and renewals, but allowed nothing for the use of dredging plant. The whole cost of removal of rock thus amounted to 6*s.* 1*d.* per cubic yard on an average.

The dredger proved to be deficient in power and weight for the work, otherwise it would have been more economically executed. As it is, the Author believes the cost is small for work of this class; and he attributes this principally to the fact that divers were employed to a very limited extent. The whole of the operations were carried out without any accident worth mention.

II. Deep-Water Quay.

The second portion of the undertaking was the construction of a deep-water quay adapted to the increased depth of water provided in the berths, and taking the place of an old wall.

A section of the new quay-wall is shown in Plate 14, Fig. 7. The general dimensions were:—Length, 712 feet; height from the bottom of the berths to coping level, 33 feet 6 inches; depth along

side at low water of ordinary spring tides, 15 feet; at high water of ordinary spring tides, 29 feet 6 inches. Height of coping above high water, 4 feet. Batter of front of piles and concrete, 1 in 13. It was executed entirely by "tide-work" without the aid of a cofferdam, and consists of timber piling and framing, and a concrete wall.

The rock was removed to the increased depth to a uniform distance of 9 feet from the face of the old quay, the remaining portion being left standing to form part of the foundation of the new wall.

Piles 36 feet 6 inches long by 13 inches square were driven into the rock forming the new bottom, to the line and batter of the front of the quay, at a distance of 8 feet apart from centre to centre. A hole was bored into the rock in the required position of the pile to a depth of about 6 feet, and a small charge of dynamite used to split the rock round the hole sufficiently to admit the pile; it was then pitched, the diver placing the shoe into the hole just fired. The piles were driven by steam from a travelling carriage upon the old quay, the leaders overhanging to the line of piles; the ram weighed 25 cwt. and the fall was always kept short, about 6 feet to 7 feet, to avoid the risk of splitting the timber owing to the hardness of the bottom. The piles drove very uniformly, the "set" at each blow gradually varying from $\frac{1}{2}$ inch at the commencement to $\frac{1}{8}$ inch at the finish. The average depth to which the piles were driven into the rock was about 5 feet. The timber was all of uncreosoted sawn pitch pine, and it was delivered on the works at the rate of 1*s.* 6*d.* per cubic foot. The pile shoes were of chilled cast-iron with four heavy wrought-iron straps, each pair of which was double-riveted through the point; the shoe was secured to the pile by twelve spikes; the weight of each shoe complete was 52 lbs. The straps protected the foot of the timber while the pile was being driven, Plate 14, Fig. 10.

Considering the nature of the bottom, the line of piles presents a very uniform appearance, any little inaccuracies that existed were afterwards rectified in the fitting of the rubbing fenders to their faces.

The piles having been driven and secured temporarily, the loose material behind the line of quay was thoroughly cleaned out by a "Priestman" grab assisted by a diver.

The temporary front planking forming the mould for the concrete was next secured to the front side of the piles from the foundation up to about 2 feet above low-water level. Only the bottom plank was permanently left in the work, and it was

secured by two 6-inch spikes at each end. The remaining planking was removed after the concrete had set thoroughly. This planking was first fixed and afterwards removed by a diver.

Concrete deposited in a liquid condition, both below and above low-water level, formed the body of the wall. The sectional area below low-water level was 82·5 square feet, and above low-water level 123 square feet, a total of 205·5 square feet. The specification for the Portland cement provided that it should be of a uniform quality, weighing not less than 90 lbs. per cubic foot, and of such a degree of fineness that 90 per cent. of it should pass through a sieve of two thousand five hundred meshes per square inch; its tensile strength was to be at least 675 lbs. on 2¼ square inches sectional area when the briquettes were seven days old, during the last six of which they were to be kept in still water. A large number of tests were made during the progress of the work, and the cement was generally found to comply with these requirements. As sea-water was largely used in mixing the concrete, the Author tested a number of briquettes made with sea-water in order to compare their strength with the fresh-water briquettes, and the result was generally in favour of those made with sea-water. The cement used throughout was of a quick-setting kind, which was best adapted to the character of the work. It was delivered alongside the quay in craft at the rate of 33*s.* 4*d.* per ton.

The cleanest and hardest of the dredged freestone rock was selected for concrete; but as it was of too soft a character to be used by itself, it was mixed in about equal proportions with granite and other hard stone, which was obtained from ships' ballast, at a cost of 1*s.* per ton. The stone was broken in a 15 inches by 9 inches Blake stone-breaker, and the material thus produced was of irregular size and shape, suitable for concrete. No large round gravel was used for making concrete, it being considered objectionable. Most of the sand required was obtained from ships' ballast, and it was generally of good quality.

The broken stone and sand were mixed in variable proportions, depending on the amount of fine material already present in the broken stone, an excess of sand being guarded against. The concrete was all mixed by hand on a wooden platform. Suitable measuring-boxes were provided, and each "batch" was about 16 cubic feet. The materials were mixed by being turned over three times dry and three times wet, the water being added gradually, and in just sufficient quantity to thoroughly wet the mixture. Below the level of 2 feet above low water the concrete

was in the proportion of 6 parts of broken stone and sand to 1 part of cement by measure; above this level the proportion was 7 to 1, and in addition large rough stones were deposited in the concrete after it was in position in the wall. This effected a saving of concrete, and formed an effectual bond between layer and layer when left projecting above each as finished.

Below low-water level the concrete was deposited under water by means of a hopper-bottomed box, of a capacity of 16 cubic feet. This appliance deposited the concrete in good condition; its construction is shown in Plate 14, Figs. 8 and 9. The concrete below low water was always deposited with the aid of a diver, who directed the position in which to lower the box, and after the deposit he gently trod it into place. About 40 feet length at a time was usually carried up from the foundation to low water, and the end of each length was finished against a cross wall of concrete bags, which prevented the concrete from running down. This portion of the work was usually executed during the high-water period, when nothing else could be done at that portion between high- and low-water levels, and in many cases the lower portion of the concrete was deposited in 28 feet depth of water. The average thickness of the concrete below low-water level, between the face of the rock and the front of the piles, was 4 feet 6 inches, the foundation level being 2 feet above the bottom outside the piles, or 13 feet below low-water level.

The concrete above low water was deposited when the tide was clear of the work, it being tipped direct from barrows on the top of the staging at the quay level. The top of the rock was first carefully cleaned, and the portion immediately above low-water level was got in during the springs at low water. From this level the concrete was brought up in layers of about 1 foot 6 inches or 2 feet in depth, the end of each layer being kept about 10 feet back from its predecessor.

At the level of 2 feet above low-water level a "step," 10 inches in width, was formed in the front line of the concrete, bringing it from the front side of the piles to within 3 inches of the back side, so that the pile from this level upwards projected through the concrete. The face planks above the "step" were secured between the piles in 7-feet lengths, and they were carefully fixed to the line and batter of the wall, the inner face being planed smooth and coated with oil immediately before the concrete was deposited. The finer concrete was selected for the front, and it was thoroughly worked down against the planks by a flat shovel, the result being, when the planks were removed, that the face presented

a smooth hard surface, satisfactory as to strength and appearance. The top surface of the quay was formed of finer concrete in the proportion of 5 to 1, properly levelled and floated. The concrete below low-water level cost 19s., and that above low-water level 12*s.* 6*d.* per cubic yard.

The main piles were connected longitudinally by two whole-timber walings, 12 inches square, the lower one at the level of 7 feet above low-water level, and the upper having its top surface flush with the coping. These were fastened on the backs of the piles, and were notched over them so as to bring the front of the timber flush with the line of the concrete. In order to tie the piles well into the concrete, 1¼-inch tie-bolts, extending from the front of every pile to the back of the concrete, were secured at the same level as, and passed through, the lower waling, and were fastened on the back of the wall to a timber upright 10 feet long by 9 inches square, let into the concrete.

The heads of the main piles were strongly tied by old 1¼-inch stud link-chains to back piles, 17 feet long by 12 inches square, driven through the old ground into the rock, at a distance of 35 feet back from the coping. One back pile secured two front piles, the tie-chains being arranged in the form of Y; the chains were screwed up tight by means of 1½-inch eye-bolts, and nuts at each end. Rubbing fenders, 13 inches by 6 inches, extending from the top of the piles to low-water level were secured to every front pile, and were fastened by oak trenails and wrought-iron straps. The coping waling was saved from ships' chains by a 3-inch by ¾-inch convex iron, fastened with countersunk spikes.

The space between the back of the concrete and the face of the old quay wall was filled up with chalk rubbish, firmly rammed. Mooring bollards, consisting each of a cast-iron column, surrounded by a concrete block 6 feet square, were fixed behind the new quay.

The total cost of the quay wall amounted to £8 13*s.* 9*d.* per lineal foot. This does not include any allowance for excavation of the foundation, which was all charged to removal of rock. The principal rates for the work as completed are given in the Appendix.

The cost of the works up to the end of July 1883 was £14,361, excluding all plant and contingent expenses. The sum of £1,276 was expended on plant during the progress of the work, most of which was available for other operations in the harbour on the completion of the undertaking now described.

The works were carried out by the Harbour Commissioners without the aid of a contractor.

The Engineers were Messrs. Thomas Meik and Sons, MM. Inst. C.E., to whom the Author is indebted for permission to prepare this Paper. The Author acted as the representative of the engineers on the works throughout, and Mr. John McAlpine was Superintendent of Works.

Further particulars of the cost of the works are given in the Appendix, Tables I. to V.

The Paper is accompanied by several drawings, from which Plate 14 has been prepared.

[APPENDIX.

APPENDIX.

I.—Removal of Rock. Summary of Quantities and Details of Cost.

Quantity removed			24,500 cubic yards.	
Number of holes blasted			4,500	
			s.	*d.*
Total cost of removal of rock			6	1 per cubic yard.
	s.	*d.*		
Cost of boring, per cubic yard (including all charges)	1	9		
Cost of blasting, per cubic yard	1	4		
Total cost of boring and blasting, per cubic yard			3	1
Cost of dredging, wages only (including repairs), per cubic yard	1	11		
Cost of materials (including repairs and renewals) per cubic yard	1	1		
Total cost of dredging, per cubic yard (including all charges, except allowance for interest and depreciation)			3	0
Total cost of removal, per cubic yard			6	1
Cost of removal, wages only—Boring and blasting, and dredging (including repairs and renewals)			3	7
Cost of removal, materials—Boring and blasting; and dredging (including repairs and renewals)			2	6
Total per cubic yard			6	1

II.—Removal of Rock. Notes on Quantities of Explosives used.

1.—Total weight of all kinds . . . . 20,915 lbs.

Made up as follows:—		
Gunpowder	9,095 lbs.	
Nobel's No. 1 dynamite	6,050 „	
„ blasting gelatine	4,170 „	
Tonite	1,400 „	
Lithofracteur	200 „	
Total	20,915 „	Average price. *s.* *d.* 1 1·8 per lb.

2.—Total weight deducting gunpowder 11,820 lbs. Average price. *s.* 1 *d.* 8·9 per lb.

		lbs.	oz.
Quantity per cubic yard, in first case	=	0·853 =	13·64
,, ,, second case . . .	=	0·482 =	7·71

Cost per cubic yard of rock removed.

	s.	*d.*
First case (including fuze, 2·3*d.*, and cartridge cases, 1·9*d.*) per cubic yard	1	4
Second case (ditto)	1	2

III.—New Quay-Wall. Rates of Cost of Principal Items of Work as Finished.

		s.	*d.*	
Timberwork—	Front piles	3	3	per cubic foot.
	Walings	2	6	,,
	Back piles	2	9	,,
	Sheet piling	2	6	,,
	Fenders	4	0	,,
Ironwork—	Pile shoes, front	18	0	per cwt.
	,, back	15	0	,,
	Tie-bolts	18	0	,,
	Eye-bolts	25	0	,,
	Small bolts	20	0	,,
Concrete—	Below low-water level (6 to 1)	19	0	per cubic yard.
	Above ,, ,, (7 to 1)	12	6	,,

	£	*s.*	*d.*
Total cost of quay-wall, as finished, per lineal foot . .	8	13	9

IV.—New Quay-Wall. Details of Cost of Concrete, per Cubic Yard.

1.—*Above Low-Water Level.* *Proportion*, 7 *to* 1.

	Cub. ft. Ton.	*s.*	*d.*
Cement . . .	4 = 0·16 at 36*s.* =	5	9
Stone and sand .	,, ,, =	2	3
Breaking stone and incidental charges . .	,, ,, =	1	2
Mixing and wheeling . .	,, ,, =	2	4
Planking . .	,, ,, =	1	0
Depositing by steam crane .	,, ,, =	..	
Diver depositing in place . .	,, ,, =	..	
Per cubic yard		12	6

2.—*Below Low-Water Level.* *Proportion*, 6 *to* 1.

	Cub. ft. Ton.	*s.*	*d.*
Cement	4·5 = 0·18 at 36*s.* . . =	6	6
Stone and sand	,, ,, . . =	2	3
Breaking stone and incidental charges	,, ,, . . =	1	2
Mixing and wheeling	,, ,, . . =	2	4
Planking	,, (fixed by diver) =	4	0
Depositing by steam crane	,, ,, . . =	0	9
Diver depositing in place	,, ,, . . =	2	0
Per cubic yard .		19	0

V.—Table of Wages.

1. *Boring and Blasting.*

	Per hour. s.	d.
"Blaster" (for preparing cartridges, and setting out position of holes, &c.	0	9
Borer (including shifting of rafts)	0	5½

2. *Dredging.*

	s.	d.
Master	0	6
Chief engineer	0	8½
Second "	0	7½
Fireman	0	5
Deckmen	0	5
Towage of hoppers (120 tons capacity)	10	0

3. *Quay.*

	s.	d.
Foreman	0	6¾
Diver, while diving	2	0
" ordinary	0	6¾
Labourer	0	5
Labourers (sailors)	0	5½
Craneman	0	5½

4. *General.*

	s.	d.
Smith (chief)	0	8½
"	0	6½
Strikers	0	5
Carpenter (chief)	0	7½
" (ordinary)	0	6¾

Note.—A considerable proportion of the work was done in "overtime," for which one and a quarter time ordinary rate of wages was paid.

(*Paper No. 2084.*)

"Spanish Tidal Flour-Mills."

By ALEXANDER FAIRLIE BRUCE, Assoc. M. Inst. C.E.

THE Author proposes to give a short description of the construction, working, and efficiency of the tidal flour-mills in use in Andalusia, more especially in the province of Huelva, which are, he believes, little known in England, and which are interesting not only from their extreme simplicity and primitiveness, but also as being perhaps the earliest form of wheel of the turbine class, having come down in their present mode of construction almost unaltered from Moorish times, if not from a still earlier date.

These mills are thickly studded all over the "Marismas," or salt-marshes, which border the lower portions of the Andalusian rivers, within the tidal range. They are built across the "esteros," or creeks, by which these marshes are intersected, at the most suitable points, where the firmest foundation is obtainable, and a sufficient amount of storage available, the natural capacity of the "estero" being increased by means of rough excavations, so as to retain at spring-tides from 500,000 to 1,000,000 cubic feet of tidal water. The total head rarely exceeds 7 feet at springs, and the mill is usually worked until it falls below 3 feet. A spring-tide admits of all the stones, three or four in number, being worked for about six hours. The number of stones which can be worked simultaneously is regulated by the height of the tide; they are all stopped at neap-tides. The range of an ordinary spring-tide in the esteros of the Rios Tinto and Odiel is about 14 feet, and of a neap-tide 6 feet.

As at the best the foundations of these walls are never very secure, they are built with very wide scarpments, on broad flat stones brought from considerable distances, heavily buttressed. They are never more than one storey high, the upper structure being built as light as possible. At one side there is an opening 7 or 8 feet in width, through which the tide flows; the water is retained by a heavy wooden shutter, which opens upwards, and the shutter is closed by the downward pressure of the water. Underneath the mill there are three or four culverts, about 4 feet 6 inches high by 2 feet 6 inches wide, in which are built the chambers

enclosing the wheel, or "arroyeno." The water is admitted to this wheel through a hole 17 inches high by 12 inches wide, which can be partially or wholly closed by means of a rough plank.

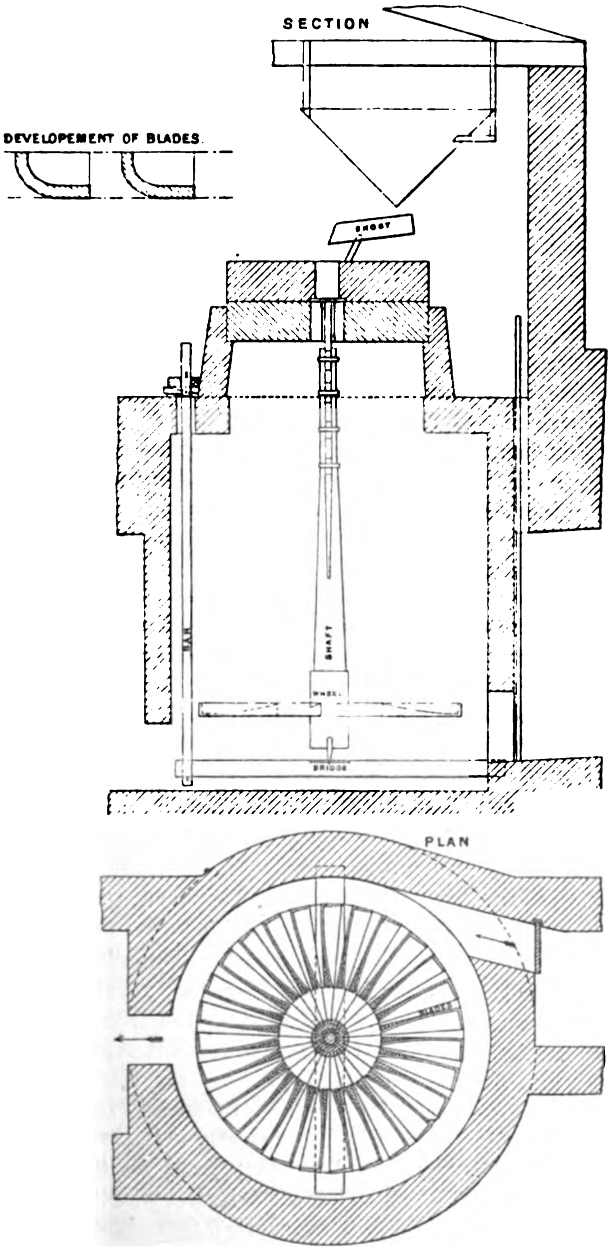
WHEEL (see Figs. p. 317).

The wheel works horizontally, and partakes perhaps rather of the nature of a dash-wheel than of a turbine, as it is actuated more by the current than by the pressure of the water. It is made of the hardest wood obtainable, with a diameter of about 5 feet 7 inches; and twenty-seven blades, called "salabés," are keyed radially into the vertical shaft, or "masa," like the spokes of a cart-wheel; they measure about $4\frac{1}{2}$ inches wide, by 3 inches deep at the periphery, are slightly curved and rounded at the back, and hollowed on the upper side, roughly-hewn logs, divided into four longitudinally, being used for the purpose. There is a considerable space between the wheel and the brickwork, allowing a large quantity of water to escape unutilized.

The masa has a diameter of about 10 inches for 8 inches above and below the wheel, and tapers upwards to about $4\frac{1}{2}$ inches below the lower stone. It communicates the power directly to the upper stone by means of an iron bar $1\frac{3}{4}$ inch square, secured in a slit in the masa by iron rings, tightened with wedges; it passes through a bush, sometimes of brass, sometimes of hard wood, in the lower stone, and the head fits into an iron plate about 2 inches by 12 inches long, sunk into the lower side of the upper stone. The masa is pivoted below by an iron spike passing through a plate nailed to a wooden beam, called the "puente," or bridge, which rests at one end in a hole in the brickwork, the other end being supported by a wooden bar called the "cacheto." The latter passes through a hole in the floor, and is fitted with a large flat head, resting on ridges by means of which the cacheto can be raised and lowered, and thus the wheel is kept level. The life of this wood-work is generally from ten to twelve years.

MILLSTONES.

The stones are usually about 4 feet in diameter, and 13 inches to 14 inches thick when new, and are used till their thickness is reduced to about 6 inches, by wear and dressing, the stone being turned over and faced whenever the grinding surface becomes pitted. The quality of the flour is regulated by the degree of fineness to which this surface is dressed. The stones are mostly



Scale ¼ inch = 1 foot.

procured from quarries in the neighbourhood of Jerez, and they last about one year.

The corn to be ground is placed in a box of the form of an inverted pyramid, which holds a "fanega," equal to rather over 1½ bushel; it is delivered through a circular hole in the upper stone, by the "canaleto," a small wooden shoot, from which the grain is shaken by a stick tied to it, and resting on the stone whose revolutions keep it constantly in motion.

Work done.

These mills can easily be managed by one man and a boy, where the number of stones does not exceed three or four, and they grind, on the average, nearly 1½ bushel per stone per hour, with an average velocity of fifty revolutions a minute; the number of revolutions per minute varies from thirty-five to sixty-five, and the average HP. developed by each wheel is nearly 0·7, thus executing less than one-half the amount of work per HP. done in an English mill.

Efficiency.

The Author has made a number of observations and calculations of the efficiency of different wheels of this construction, and, as might be expected, from the extreme roughness of their design, has found it to be very low; it rarely exceeds 0·10, and occasionally, when the head is very small, it falls so low as 0·05, 0·09 being about the average, the theoretical efficiency of water being taken as unity. In fact the only arguments in their favour are their cheapness, in first cost and repair, and the ease with which they are looked after.

Improved Wheel.

An improved system of turbine wheel is beginning to supersede the above, and gives much better results. It also is made of wood, and is much more closely related to the true turbine. The usual dimensions of these turbines are about 3 feet 2 inches in diameter, and 5 inches deep; they have six blades or buckets, with a development similar to that of Jonval's turbines, and a wooden periphery, or tire, which fits closely to the brickwork of the chamber in which they revolve; they have no guides, and the water is admitted through a channel 8 inches wide, in a direction tangential to the wheel. An overflow, 5 feet above the wheel, is pivoted in a rather ingenious, if not very scientific way; the pivot

consists of a cruciform brass casting; each of the four arms is 2 to 3 inches long, and tapers from 1 inch to $\frac{3}{4}$ inch in diameter, with a blunt point $\frac{1}{4}$ inch in diameter; one arm is inserted in the butt of the masa, and that opposite rests on a cube of brass of 2 inches diameter, slightly indented, on which it is allowed to work until it has penetrated to a depth of about $\frac{3}{4}$ inch, when the wheel is lifted, and another side of the cube is turned up and another point brought to bear on it, till all four are in turn worn out. The bearing is supported by a block of marble, or other easily-dressed stone.

Work and Efficiency.

These wheels develop an average of $2\frac{1}{4}$ HP., and grind about $2\frac{1}{3}$ bushels per hour with a velocity of from forty-five to ninety-five revolutions per minute, according to the head of water, the average being from seventy-five to eighty. The work done is nearly the same as by an English stone per HP. The peripheral velocity of both this wheel and that already described, is nearly that of the current of water passing through them. The improved design of these wheels of course gives them a great advantage in point of efficiency over the older form; it usually ranges from 0·31 to 0·38, and might easily be greatly increased by using a better form of pivot, guides, &c.

In conclusion, it may be remarked that, although the primitive form of wheel possesses little beyond an antiquarian interest, the more improved form might, in the opinion of the Author, be adopted in out-of-the-way places where skilled labour is difficult to obtain, and water is plentiful.

The Paper is accompanied by a drawing from which the figures in the text have been engraved.

OBITUARY NOTICES.

GEORGE FREDERICK ADAMS was the only son of the late Mr. George Adams of Aberdare, the Manager of the Aberdare Iron Company's property, and was born on the 9th June, 1842, at Ebbw Vale. He was educated at the Normal College School, Swansea, and at Cotham School, Bristol, and afterwards in the Engineering Department of King's College, London, where he obtained the practical scholarship in 1862. He then passed to the engineering shops of the Ebbw Vale Iron Company at Ebbw Vale, Monmouthshire; his uncle, Mr. William Adams, M. Inst. C.E., being then General Manager of the Company. After three years in the practical mechanical department at Ebbw Vale, he was articled in 1865 for three years to the late Mr. Samuel Dobson, M. Inst. C.E., and at the expiration of his pupilage he became the chief-assistant to Messrs. Dobson and Brown at Cardiff, and in the beginning of 1870 was taken into that firm, which became Dobson, Brown, and Adams. Mr. Dobson died in July, 1870, and as a partner in the firm of Brown and Adams, Mr. Adams was continually engaged, until his health broke up in 1883, in extensive engineering works, civil and mining. In civil engineering—the extension of the Llynvi and Ogmore Railways into the Avon Valley, the Ely and Clydach Valleys Railway, works on the South Wales Mineral Railway and other works, and in mining—the carrying out of extensive winnings for steam-coal in South Wales and Monmouthshire, one of which, the sinking of the Harris's Navigation Colliery, was made the subject of a joint paper by himself and his partner, Mr. Forster Brown, read before the Institution in the beginning of 1881,[1] and in respect of which Telford Premiums and Stephenson Medals were awarded to the Authors. Mr. Adams also assisted Mr. Brown in the preparation of a Paper upon the South Wales Coal-Field, read before the North of England Institute of Mining and Mechanical Engineers when they visited Cardiff in the year 1874. One of the last works in which Mr. Adams was engaged was the preparation of plans and sections and preliminary arrangements in conjunction with Mr. J. Wolfe Barry, Mr. H. M. Brunel, and Mr. Forster Brown, for the Barry Dock and Railway Scheme in

[1] Minutes of Proceedings Inst. C.E., vol. lxiv., p. 23.

the autumn of 1883. Early in 1882 Mr. Adams caught a severe cold, which settled upon his lungs, and although after this he spent a great part of his time in the Riviera, his health continued to decline, and he died at his residence, Keswick House, Cardiff, on the 10th of October, 1884. He was especially well-informed; amiable in disposition, and unusually popular with all with whom he came in contact, either socially or in business, and he was mourned by many friends. In his profession his judgment was sound, and he was especially expert in all arrangements which involved the application of machinery.

Mr. Adams was elected a Member of the Institution on the 30th of May, 1876.

PETER WILLIAM BARLOW, whose death occurred on the 19th of May, 1885, was the eldest son of the late Professor Barlow. He was educated at private schools, and, having at an early age selected civil engineering as his profession, became a pupil of the late Mr. Henry Robinson Palmer, M. Inst. C.E., under whom he was engaged on the Liverpool and Birmingham canal, and the then New London Docks. The active demand for railways which followed the opening of the Liverpool and Manchester line, caused him to be employed in the preliminary surveys and studies of the county of Kent, with reference to a railway to Dover, and in 1836 he acted as Resident Engineer, under the late Sir William Cubitt, on the central division of the London and Dover railway, which formed the nucleus of the present South-Eastern system. He subsequently became Resident Engineer of the whole line, and afterwards Engineer-in-Chief, during which period he constructed the North Kent, the Tunbridge and Hastings, and many other extensions. In 1842 he designed and executed the Tunbridge Wells branch, which line was remarkable from the fact that it was executed before the Act was obtained by the consent of the landowners and occupiers. He also constructed the Londonderry and Enniskillen, the Londonderry and Coleraine, the Newtown and Oswestry, and other railways.

In 1858 Mr. Barlow investigated in great detail the construction of bridges of large span, especially with regard to stiffening the roadways of suspension bridges. He demonstrated, by experiments on models of large size, the possibility of stiffening suspension bridges by comparatively light parallel girders extending from pier to pier, and he proved that, by this mode of construction, the total weight of metal required for a stiffened suspension bridge

would be much less than that required for an ordinary parallel girder of equal strength and stiffness for the same span.

Professor Rankine, who subsequently investigated the problem mathematically, confirmed Mr. Barlow's deductions, and says in his later editions of "Applied Mechanics," that "if mathematicians had directed their attention to the subject they might have anticipated this result." It is to be remarked, however, that these investigations apply to the employment of parallel girders extending from pier to pier, and that the conditions become entirely altered when girders of the form called "cantilever girders" are employed.

In pursuance of these studies Mr. Barlow went to Niagara, in order to examine personally the great railway and road bridge erected there by Roebling. On his return a company was formed for constructing a bridge across the Thames at Lambeth, of which he was appointed Engineer. In this work, which is a wire rope suspension bridge, he introduced diagonal struts in connection with the vertical ties by which the roadway is suspended, and in this way a degree of stiffness was obtained nearly equal to that of girders of like span, and sufficient to enable large gas-mains to be laid across the bridge without any leakage. This bridge has since been purchased by the Metropolitan Board of Works, and, like the Waterloo, Vauxhall, and other Thames bridges, has been made free of toll.

During the construction of Lambeth Bridge, the process of sinking, or forcing into the clay, the cast-iron cylinders which formed the piers, suggested to Mr. Barlow the idea that such cylinders could with facility be driven horizontally, and that tunnels could be made under rivers by this means in suitabl soils. In order to carry out this idea, a site for the work was selected near the Tower, where considerable traffic crossed the river by ferries, and where the river-bed is formed of solid London clay, and a company was formed to carry out the undertaking. The work was commenced by sinking a shaft on the north side, from which the tunnel was driven. The tunnel itself is composed of cast-iron cylindrical rings, formed of segments, each ring being 18 inches long. A shield was used somewhat similar in principle to that employed by Brunel in the Thames Tunnel. It fitted loosely the outside of the cylindrical rings, and was about 6 feet in length. This shield was forced forward by screws, so as to permit of the cylindrical rings being put together between the face and the excavated work. As the shield moved forward, a small space was left outside the rings, which was filled by in-

jecting fluid cement-concrete. The operation was perfectly successful, and was carried forward so rapidly that the length under the river, viz. 900 feet, was executed in fourteen weeks. The top of the tunnel is about 25 feet below the bed of the river in the middle of the stream, and the paddle wheels of steamers could be distinctly heard in the tunnel; yet the tunnel was perfectly dry throughout its whole length. Although this work is of small dimensions, and only adapted for foot-passengers, yet its cost was very small, and it is extensively used by the working classes, who were formerly entirely dependent on the ferries.

The Lambeth Bridge and the Tower Subway were the two latest public works executed by Mr. Barlow.

Subsequently he suffered from an attack of cataract, which entirely deprived him of sight for some months, but a successful operation partially restored the use of one of his eyes. He was not, however, able any longer to pursue his profession with that energy and activity which characterised his earlier life.

Mr. Barlow was the author of several scientific Papers, among which may be mentioned "An investigation of the laws which govern the motions of steam vessels" (Phil. Trans., 1834, pp. 309–332); "On the strains to which Lock Gates are subjected" (Trans. Inst. C.E., i., 1836, pp. 67–80); "Investigation of the power consumed in overcoming the inertia of Railway Trains, and of the resistance of the air to the motion of railway trains at high Velocities" (Roy. Soc. Proc., v., 1846, pp. 606–607); "On some Peculiar Features of the Water-bearing Strata of the London Basin" (Min. of Proc. Inst. C.E., xiv., 1854–55, pp. 42–95); "On the Mechanical Effect of combining Girders and Suspension Chains" (Brit. Assoc. Rep., 1857, pp. 238–248); and "Observations on the Niagara Bridge" (Franklin Inst. Journ., xli., 1861, pp. 16–22, 89–94, 160–166).

Mr. Barlow became a Fellow of the Royal Society in 1854. He joined the Institution of Civil Engineers in 1827, and at the time of his death was the oldest member of the Institution.

JAMES BOLLAND was born in Liverpool on the 27th of January, 1835. His parents having removed to Chester, he was educated at a private school in that city, and at an early age he became a pupil in the office of the late Mr. W. Bragge, at that time the engineer of the Birkenhead, Lancashire, and Cheshire Junction Railway, and for whom he was engaged to about the year 1852,

upon the projected Parahiba Railway, Brazil. In 1853–54, he was the resident engineer during the construction of the Rio de Janeiro Gasworks; and for two years held a similar position under the late Mr. E. B. Webb, M. Inst. C.E., on the Mangaratiba High Road, in the province of Rio de Janeiro. He was afterwards occupied on the preliminary surveys of the São Paulo Railway, under Mr. D. M. Fox, M. Inst. C.E. In 1858–59 he was employed, by the late Mr. W. Marchant, on works of construction (afterwards abandoned) of an inclined-plane railway up the Tijuca Serra, in the neighbourhood of Rio de Janeiro. In 1860, on the commencement of the construction of the São Paulo Railway, he was appointed resident engineer of the Serra section, Mr. James Brunlees, Past-President Inst. C.E., being the Engineer-in-chief, and did important work in laying out that difficult length of line. He was then engaged, for Mr. E. B. Webb, on the original surveys of the Paraguassu Railway, now the Bahia Central Railway, in the province of Bahia. During the years 1864–67, in conjunction with Mr. Webb, he made surveys and studies for two lines of railway in the Spanish colonial island of Porto Rico, as well as for irrigation-works, and for waterworks for San Juan, the capital; but these works were not carried out. Subsequently he was in general practice in Westminster, during which time he was connected with projects for various works in Spain, and was consulting engineer of the Newfoundland Railways. In 1874 he prepared a comprehensive scheme for an iron-breakwater and harbour at Buenos Ayres, of which Mr. Brunlees was consulting engineer; but the project was not carried out. He died of congestion of the lungs, on the 30th of March, 1885, after a few days' illness. Mr. Bolland had been a Member of the Institution since February 1867.

AILSA JANSON (named after his godfather the Marquess of Ailsa) was born in January 1844, at Richmond in Surrey, where his family then resided, and he died of yellow fever, at Pernambuco, on the 28th of April, 1885, at the early age of 41.

Ailsa Janson was the only son of Henri Etienne Janson, formerly an officer in the French Army, and subsequently one of the tutors to George V., King of Hanover. The father, wishing his son to enter the French military service, took entire charge of his education up to the age of 16; but the sympathies of the son being essentially English, and the father objecting to his joining the British Army, his education was completed with a view to his

following the profession of a civil engineer. After spending about a year at a private school in Paris, he went—at the instance of his father's friend and former pupil, the late King of Hanover—to the Polytechnic School of Hanover, where he had the advantage of studying under Professor Rühlmann and other distinguished men attached to the professional staff. The course usually extends over four years, but by close application young Janson completed his studies in three years; this success may probably be ascribed, to some extent, to the sound methods, and the knowledge of modern languages, acquired under his father's tuition. Concurrently with his studies in Hanover, Ailsa Janson had some practical work on the Lüneburg-Lauenburg and on the Gössnitz and Gera Railways, then under construction.

In 1865 and 1866 he was employed by the late Mr. Tolmé, M. Inst. C.E., on the Gellivara Canals in Sweden, and in 1868 as assistant to the late Mr. Blair, M. Inst. C.E., in making the engineering surveys and calculations for the regulation of the Danube at Vienna. In 1869 he was engaged in the construction of the Grosswardein-Klausenburg Railway, about 100 miles in length, and had charge of the preparation of the working drawings. In 1871 he was Resident Engineer on a section of the East Hungarian Railway, which included the important terminal station of Maros-Vásárhely, and from 1872 to 1875 was similarly occupied on the main line from Gyéres to Kocsárd, on which length there were two tunnels, large iron, timber and stone bridges, and heavy earthworks in slippery ground requiring special precautions.

In 1875, on the recommendation of Mr. Fowler, Past-President Inst. C.E., Consulting Engineer to the Egyptian Government, he was entrusted by His Highness the Khedive with the construction of the Soudan Railway, then proposed to be carried out from Wady Halfa to a distance of about 150 miles, whence there is uninterrupted water-communication with Khartoum. The surveys for the line had been made under Mr. Fowler's direction, and largely under his personal supervision; but, with a view of creating a staff of native engineers, the final surveys and the execution of the works were entrusted to Egyptian engineers, under Mr. Janson's guidance and direction, and the only contract was with Messrs. Appleby Brothers for the permanent-way materials, rolling stock, &c., which they delivered to the Soudan Railway Stores in Egypt. Mr. Janson's sound education and singular faculty for acquiring languages proved of great value in this service, and early in 1878 the late General Gordon, by order of His Highness

the Khedive, made him Director of Works in the Soudan. Owing, however, to financial pressure on the resources of Egypt, the works on the Soudan Railway were soon afterwards abandoned, and, unfortunately for the country, have never been carried out.

In 1879 Mr. Janson was appointed Engineer and General Manager of the Great Western Railway of Brazil, Mr. Charles Neate, M. Inst. C.E., being the consulting engineer. The works were commenced by the contractors, Messrs. Wilson, Son, and Co., in March 1879, and the line was formally opened in October 1881 as far as Páo d'Alho, the whole line and the branch being completed in September 1882. In addition to the routine-work incidental to the construction and subsequent management of 60 miles of railway with an increasing traffic, aided by a very slender European staff, Mr. Janson completed surveys and estimates for an extension of the line, 30 miles in length, and conducted protracted negotiations on the subject with the Brazilian Government, involving several visits to Rio de Janeiro. His energies were further taxed, for the last two years of his life, by a series of complicated law-suits in the Brazilian Courts, the proceedings in which were successfully concluded only on the very day of his death. It seems probable that a long course of excessive work, with much anxiety, in a tropical climate, may have enfeebled his naturally very strong constitution, and rendered him more sensitive to the influence of the fever which carried him off after a few days' illness.

Mr. Janson possessed a thorough knowledge, both theoretical and practical, of his profession; he had good administrative abilities, and was an indefatigable man of business. He also possessed linguistic and other accomplishments in a high degree; he united with a cultivated mind and polished manners great geniality of temperament and goodness of heart.

Mr. Janson was remarkably popular with his assistants, whose esteem and devotion he always commanded; his success with workmen and officials in so many countries may have been due to some extent to his educational advantages, but they were probably far more so to his unswerving rectitude and his patience even under great provocation. The esteem in which he was held at Pernambuco was shown by the general suspension of business when his death was made known, and by the large concourse which followed him to his grave.

The Directors of the Great Western of Brazil Railway Company, and especially the Chairman—Mr. Frank Parish, who had a long personal intercourse with Mr. Janson—held in the highest

estimation his character and abilities, and have endeavoured to do honour to his memory, recognizing in him a rare combination of qualities which would have made him an invaluable manager or representative of any railway company in a foreign country, and which were never displayed to greater advantage than during his representation of the interests of the Great Western of Brazil Railway.

Mr. Janson was elected an Associate of the Institution on the 3rd of December, 1872, and was transferred to the class of Member in May, 1878.

CHARLES MANBY died, in the eighty-first year of his age, on the 31st of July, 1884. His name will be well known to every member of the Institution as having filled, for nearly half a century, the office of Secretary (acting or honorary); but only those who have been more especially familiar with the management and progress of the body during this time can properly appreciate the benefit it has derived from his services. It is not too much to say that the great prosperity of the corporation, and the unexampled position it occupies among scientific and technical associations, are due largely to him.

He was born on the 4th of February, 1804, and was the eldest son of Mr. Aaron Manby, an engineer and member of the Institution, who had established a large engineering factory at Horseley, a few miles from Birmingham. This establishment was devoted to the design and construction of steam-engines, machinery, and ironwork of all kinds. It was conducted by the elder Manby with great skill and enterprise for many years, and it has ever since retained a high reputation in the world of mechanical engineering.

Charles's early education was received at a Roman Catholic seminary, whence he was sent in 1814 to the semi-military college of Saint Servan, in Brittany, with the object of gaining a knowledge of foreign languages, and of preparing him for a military career, which it was then intended he should adopt. His uncle, Captain Joseph Manby, who was A.D.C. and Private Secretary to Prince Edward, Duke of Kent, had obtained for him a commission in the army. But this was soon resigned; the expectation of universal peace, which sprang up after the Battle of Waterloo, having induced his father to withdraw him from a pursuit which no longer seemed to promise beneficial employment. Young Manby accordingly returned to England in 1815, and after a short interval, devoted to mathematical and scientific studies, he entered the ironworks established by his father.

The varied nature of the work carried on at Horseley gave him an excellent opportunity of acquiring engineering experience, and he was not slow to avail himself of the advantages thus presented. After a short period spent in the workshops, he was sent out by his father in charge of important contract work of all kinds. He worked for some time in the West India Docks under the elder Mr. Rennie, and subsequently under Mr. Telford, the first President of the Institution.

Among the works thus entrusted to Charles Manby by his father was one of special historic interest, namely, the building and trial trip of the first iron steam-vessel that ever made a sea voyage. The following notice of this work was given by Sir John Rennie in a presidential address delivered before this Institution on the 20th of January, 1846:—"Neither must we forget the very important improvement in the introduction of iron for the construction of vessels, which enables us to combine lightness and elegance of form with strength and durability. For this valuable addition to marine architecture we are indebted to Aaron Manby. In 1820–21 he constructed at Horseley, near Birmingham, a wrought-iron boat, called the 'Aaron Manby,' 120 feet long and 18 feet beam, and when laden drawing 3 feet 6 inches water. It was propelled by Oldham's feathering paddle-wheels, worked by a single engine of 80 H.P., and was built for the purpose of plying on the river Seine. The boat was completed in 1821–22, and was navigated across the Channel by the present Sir Charles Napier, who was deeply interested in the undertaking; it was not only the first iron vessel that ever made a sea voyage, but also the first that conveyed a cargo from London to Paris direct, without transhipment. She continued plying between Paris and Havre for several years, until superseded by other more powerful and improved boats; the hull is yet in existence, and is still used with new engines on board, as are three others which were built about the same time." The "Aaron Manby" arrived in Paris on the 12th of June, 1822. At that time Charles Manby was barely 18 years old, and he had not only put the engine into the vessel, but had served as Chief Engineer during the voyage.

Another mechanical matter of history on which Charles was engaged during this period was the design and construction of the first pair of marine engines having oscillating cylinders. This contrivance was invented by Aaron Manby, and was carried into execution in 1821. The original drawing of these engines, made by Charles Manby, is preserved in the Institution.

In the year 1819, Mr. Aaron Manby established an iron-foundry

at Charenton, near Paris, the management of which he had entrusted to the late Mr. Daniel Wilson, M. Inst. C.E. Mr. Manby had taken a very active part in the introduction of lighting by gas, and for several years he had been making persistent efforts to obtain a concession for lighting Paris in this way, and had taken out a patent for gas-lighting in France on July 12th, 1821. He met, however, with considerable opposition from a rival firm, and it was not until 1823 that his efforts were successful, when Manby and Co. were granted the privilege of lighting Paris by gas. Charles Manby then went to Paris, and undertook the construction of the gas-works and the operation of laying the pipes in the streets, tasks he successfully performed, though he had to contend with great difficulties, amongst which the inexperience of the French workmen was not the least. On Mr. Daniel Wilson assuming the administration of the gas-works, Charles Manby took charge of the Charenton foundry, where he constructed a number of marine engines for the French Government and for private companies, as well as machinery of various kinds for the ironworks which were then springing into existence all over France. Thence he removed to the now famous Creusot Ironworks, which his father had undertaken to reorganise, and, after remaining there for a short period, he was employed by the French Minister, Count Benoist d'Azy, in the construction of the State Tobacco Manufactories, and was appointed Chief Engineer of the Tobacco Department of Public Works. At the same time a commission in the French Military Engineers was given to him through the friendship of Marshal Soult.

Towards the end of 1829 Charles Manby returned to England, and undertook the management of the Beaufort Ironworks in South Wales, where he remained for some years. He was then for a short time connected with the Ebbw Vale Iron Company, when he introduced several ingenious modifications in the rolling of rails. He was next engaged for a few months at the Bristol Ironworks, and finally removed to London in 1835, where he commenced practice as a Civil Engineer. For a time he devoted himself principally to the introduction of a system of warming and ventilating buildings, known as Price and Manby's system, which was used extensively in many important buildings in London and elsewhere. In 1838 he was appointed Engineer to a Steamship Company, established in London by Sir John Ross, to run steamers between England and India. Only one vessel, the "India," was built, and this vessel was afterwards bought, and the Company absorbed, by the Peninsular and Oriental Steam Navigation Company.

On his acceptance of the office of Secretary to the Institution in 1839, he relinquished professional practice, but in 1856 he, at the urgent request of Mr. Robert Stephenson, took the position of London representative of the firm of R. Stephenson and Company, of Newcastle-on-Tyne, which he retained till he died.

But the most important duty in this notice of Charles Manby is to chronicle his connection with the Institution, to which he devoted the best energies and the best years of his life.

He was elected an Associate on the 2nd of May, 1837, and a year or two afterwards, it having been noticed that he possessed qualifications remarkably suitable for the official duties of an important society, he was invited, at the instance of Messrs. Simpson and Bramah, to undertake the post of paid Secretary, the office having previously been filled honorarily. He accepted it, and he was appointed on the 21st of June, 1839.

The engineering history of this country was at this period entering upon a stirring phase, and the new Secretary resolved to devote his time, his talents, and even his means, to extending the influence and raising the character of the Society, and making it a body which should be worthily representative of a great profession. Soon after his election, he threw himself heart and soul into a movement which revolutionized the Society. The Presidential Chair had been held for ten years by Mr. James Walker, who seemed to regard it as a life-honour, as it had been in the case of Thomas Telford, the first President. It was felt, however, by many rising men, especially by those connected with the great railway-works then in progress, that the Chair should be open to other eminent members of the profession. After some stormy debates, Mr. Walker retired, new by-laws and rules were framed, and the Chair has since been filled in rotation by men whose names have added lustre to their calling. For many years Charles Manby appeared to live solely in and for the Institution. Thanks to his unwearying exertions the number of members rapidly increased, the finances improved, and the reputation of the body extended. Eminent men in all branches of science attended its meetings, and the leading statesmen and noblemen of the country came to the *Conversazioni*, feeling that it was a matter of duty to contribute to the development of an association so thoroughly representative of the technical skill and the intellectual energies of the nation. It is no disparagement to successive Presidents and Members of Council to say that a very large measure of the progress thus achieved was due to the ability, devotion, and

energetic action of their Secretary, and in fact this sentiment and conviction have long been universal.

In 1856 (when he undertook the duties already mentioned for the firm of Robert Stephenson and Co.), feeling that he had done seventeen years good work in bringing the Institution to such a prosperous position, he expressed a wish to be relieved of his more arduous labours; and accordingly the duties of Acting Secretary were confided to his old pupil, Mr. James Forrest, Mr. Manby retaining the post of Honorary Secretary, which he filled until his death. His leave-taking was the occasion of a very cordial demonstration of the esteem in which he was held by the members, and by his personal friends. Four hundred and seventeen of them joined together in presenting him with a service of plate and a purse of £2,000. These offerings were presented to him at a special meeting on the 23rd of May, 1857, by Robert Stephenson, then President, "as a token of personal esteem, and in recognition of the valuable services he had rendered to the members individually and collectively." In acknowledging this mark of appreciation, he asked to be allowed to devote a portion of the sum to the foundation of an annual premium which should bear his name, and the Manby Premium now forms one of the prizes at the disposal of the Council.

Charles Manby continued until his death to work unremittingly for the interests of the Institution. His unceasing labours on its behalf were again recognised in 1876, when he received from the members a silver salver, and a purse of upwards of £4000, "in friendly remembrance of many years' valuable services."

In 1850 he was transferred to the grade of a Member of the Institution.

In 1857 he suggested the formation of a fund for the relief of members of the engineering profession who might be in distress; but nothing was done until seven years later, when "The Benevolent Fund of the Institution" was successfully established by the zeal and energy of Mr., now Sir, Frederick Bramwell.

Those who only knew Charles Manby in his declining years can hardly realise the value of his services to the Institution and to the profession generally. His was no mere official position, he formed personal intimacies with large numbers of the members, and took a pride in holding himself at the disposal of any and every one who wanted his aid, from the President down to the most humble individual. He advised, assisted, and encouraged the young, and was the trusted friend and counsellor of the old; many of the former have gratefully acknowledged their after

success in life as largely due to his aid; while many of the latter have had to thank him for essential and important services in difficult and critical points of their career.

The prominent position Mr. Manby occupied caused him to be often applied to for important services of various kinds.

In 1851, at the period of the projected International Exhibition, he was entrusted by Sir Robert Peel with some of the preliminaries of that new and vast undertaking. The idea of the guarantee fund emanated from him; in one day he obtained the guarantee of £10,000; on the following day Sir Morton Peto put down his name for £50,000, and thus the success of the movement was assured.

At a later period he was named, conjointly with Mr. J. M. Rendel and Mr. J. R. McClean, a member of the International Scientific Commission which was held at Paris, for the purpose of considering and reporting on the practicability of constructing the proposed Suez Canal. Mr. Manby was then elected one of the Secretaries of the Commission, with Mr. Barthélemy Saint-Hilaire, and Lieutenant Lieussou, as his colleagues. But they all resigned their functions when the Company commenced commercial operations.

The desire to widen the usefulness of the engineering profession led Charles Manby, in the year 1864, to take an active part in the establishment of the Engineer and Railway Volunteer Staff Corps, the official business of which was subsequently to a large extent carried on by him. This corps consists of engineers, railway managers, and contractors, and was constituted "for the purpose of directing the application of skilled labour and of railway transport to the work of national defence, and for preparing in time of peace a system on which such duties should be conducted." In this corps he held till his death the post of Adjutant, with the rank of Lieutenant-Colonel, a title of which he was always very proud.

Mr. Manby's early continental associations, and his perfect knowledge of the French language, made him well known to foreigners connected with science or technical matters. He was consequently often applied to by them for aid, and the services which he was enabled to render to strangers from all parts of the world, have been universally recognised. On the occasion of her Majesty's coronation, Marshal Soult was deputed to represent France as Minister Plenipotentiary, and Charles Manby, who during the Marshal's visit never left him, successfully organised and arranged a series of inspections of public works, receptions, and banquets, for which he received the thanks of the King of the French in more than one autograph letter. All foreign engineers

visiting this country obtained, through his influence, a cordial welcome amongst their English brethren; while his extensive foreign relations were always at the disposal of English professional men to assist them on their travels.

Mr. Manby had a large circle of friends and acquaintances outside science and engineering. He had, at an early period of his residence in London, formed a close friendship with an eminent personage in the theatrical world, and in pursuance of certain testamentary dispositions he found himself obliged to assume the business management of the Adelphi and the Haymarket Theatres. Foreign as this duty was to his ordinary vocations, he loyally performed it for many years with great energy and perseverance, and his excellent judgment and businesslike habits were of the greatest advantage to the interests he represented. This connection brought him into contact with many celebrities in the artistic and literary world, and introduced him into many clubs and coteries where he was always a favourite.

In private life Charles Manby was deservedly liked by all, loved by many. His many attainments and versatile natural powers made him a charming companion. The great variety of men—scientific, artistic, and literary—whom he was intimate with, indicated the peculiar attractiveness of his character. He was constant and loyal to his friends, in whose interests no efforts were too great for him. It was well said by one who knew him well, that the greatest favour a person could do him was to ask a favour from him. But it must be acknowledged that, while none could be warmer or more constant in attachment, so, on the other hand, as a partizan or as an opponent he was very human, and the grey eye that shone with a woman's tenderness on a friend, lighted up with an unmistakable fire on a presuming or obstinate opponent. The stuff that was in Charles Manby was typical of the spirit that has raised the profession to its present state—a determined will, guided by an intelligent brain, and ordered by the discipline of a thorough man of business and of the world.

In 1853 Mr. Manby was elected a Fellow of the Royal Society, and in 1867 an Honorary Member of the Institute of Civil Engineers of Holland. He was an officer of the Legion of Honour (France), and Knight of the Orders of St. Maurice and St. Lazarus (Italy); the Rose (Brazil); Wasa (Sweden), and the Medjidie (Turkey).

Although, from the nature of his social relations, he had many temptations to live what is called a fast life, he was exceedingly temperate, moderate, and even self-denying in his habits, and he reaped the full benefit of this in his continual good health and

power of work. He retained these to a ripe old age; he resided, during the latter part of his life, on the estate of his step-son, Mr. Arthur Hood, at Eastbourne; but he had also an official residence in London where he passed many days every week, and where he was taken ill, and died by pure decay of nature.

He was twice married, first in 1830, to Miss Ellen Jones, of Beaufort, and secondly in 1858, to Harriet, daughter of Major Nicholas Willard, of the Greys, Eastbourne, and widow of Mr. W. C. Hood, formerly a partner in the publishing house of Whitaker and Co. He left no issue.

The portrait which forms a frontispiece to this volume has been engraved from a photograph taken by Messrs. Lavis, of Eastbourne, a few years ago.

JOSEPH D'AGUILAR SAMUDA was born in London, in the year 1813, and was the son of Mr. Abraham Samuda, an East and West India Merchant of Finsbury, by Joy, daughter of Mr. H. D'Aguilar, of Enfield Chase. He studied as an engineer under his brother Jacob Samuda, with whom he became a partner in the year 1832. During the ten years between 1832 and 1842, the operations of the firm of "Samuda Brothers" were principally confined to the building of marine engines. In the year 1840, attention was largely drawn to experiments carried out on Wormwood Scrubs having for their object the application of atmospheric pressure to the propulsion of railway trains. Mr. S. Clegg and Mr. Jacob Samuda having turned their attention to the subject, patented a scheme for atmospheric railways, which the firm of Samuda Brothers were engaged in putting into practice between the years 1842 and 1848. They laid down and worked experimental lines at Dalkey, Croydon, Paris, and other places; but the practical difficulties connected with the system were so great as to prevent its general adoption, and it was eventually abandoned. In the year 1843 the firm commenced that shipbuilding business which soon established a reputation for itself, and has since made the name of Samuda so widely known. One of the first vessels built was the "Gipsy Queen," a name carrying with it painful associations, for it was on board of her that Mr. Jacob Samuda lost his life, in 1844, by the giving way of a defective expansion joint, during a trial of the engines. From the year 1843 until the present time the firm of Samuda Brothers has been uninterruptedly engaged in the construction of ships of

all kinds, for both the war- and merchant-navies of this and other countries. It need hardly be said that the changes and improvements that have taken place during that period in ship-construction have been enormous and numerous, and most of them are to be found reflected in the ships built by Mr. Samuda. Indeed a sufficiently detailed account of the shipbuilding operations of the firm of Samuda Brothers, from the year 1843 to the present time, would constitute an excellent history of the rise, progress, and development of iron steam-ship construction. In their yard on the Isle of Dogs are found most of the time- and labour-saving machines which have at intervals been introduced for the more accurate and more rapid preparation and manipulation of the materials used in the many departments of the art. Among these especially worthy of mention is a hydraulic armour-plate bending machine, which has been at work for many years, and is capable of exerting a working pressure of 70 cwt. per square inch, or a total pressure of 4,000 tons. An enumeration of the vessels built by Mr. Samuda would be tedious. Suffice it to say, that it would include many of the most noted steamers of the leading mail- and passenger-services, many iron-clad men-of-war for the British and other navies, many vessels for other branches of naval services, besides Royal yachts, channel steamers, river-boats, &c. The excellence in ship-construction, to which the firm attained under Mr. Samuda's control, is well illustrated by some of the vessels of war lately built by them, notably the two most recent iron-clads, the "Riachuelo" and the "Aquidaban," belonging to the Brazilian Government, and also by the three famous channel steamers, "Albert Victor," "Louise Dagmar," and "Mary Beatrice," which ply between Folkestone and Boulogne. These ships are justly looked upon as embodying the most recent developments of the practical shipbuilder's art in a more economical and effective manner than has before been accomplished with vessels of similar types.

On the 6th of May, 1862, Mr. Samuda became a Member of this Institution, though he had been an occasional visitor at its meetings for many years previously. It was at the discussion of a Paper, by his brother, Jacob Samuda, on the atmospheric railway system, previously spoken of, that he first attracted attention as a debater. The Secretary, Mr. Charles Manby, was so struck by his fluent diction, as well as by his thorough mastery of the subject, that he immediately set about to attract to the meetings outsiders of as near Mr. Samuda's calibre as might be, in order to import more character into the somewhat slow and decorous style of the discussions, as they then obtained. Mr.

Samuda contributed one Paper only to the Proceedings, "On the Form and Materials for Iron-plated Ships,"[1] for which he was awarded a Watt medal; but his speeches, on subjects with which he was familiar, were always forcible and instructive, and often of hardly less value than the more ambitious communications upon which his comments were invited. The importance attaching to his opinion can perhaps be better understood if, while bearing in mind his great natural ability and attainments, it is endeavoured to realise what an experience of fifty years such as his comprised. In the year 1830, about the commencement of his career, the number of steamships belonging to the British Empire was three hundred and fifteen. These were all small craft employed exclusively in river- and coasting-trades, the "leviathans" among them being below 500 tons in measurement. Only a few small iron vessels had then been built, and these were merely employed in river-navigation. Iron ships were not considered safe, and none had yet been built for over-sea voyages. Compare with this the fact that three hundred and twenty-three iron and steel steamers—of various sizes up to and exceeding 8000 tons—were launched, in 1884, upon the Clyde alone, several of which make the longest sea voyage possible—viz., that from this country to New Zealand—under steam. The screw-propeller, the use of which is now universal—except where special service renders the paddle or other propeller more suitable—although known in earlier centuries, was first successfully applied to the propulsion of ships in 1836. The steam-hammer, which now occupies so important a place in all engineering works, was invented by Mr. Nasmyth in 1838. The first of the great steamship lines, which now traverse the ocean in every direction, at speeds ranging from 16 to more than 20 miles an hour, commenced running its steamers in 1840. The almost magical transition from the lumbering old stage-coach to the swift-gliding Pullman "express" is within the experience of much younger men than the late Mr. Samuda. The completion of the great Plymouth breakwater in 1841, and of the Thames Tunnel in 1843, and the building of the Britannia Tubular Bridge in 1846–50, are so many landmarks typical of the progress in various branches of engineering. The great development of naval artillery from the old 68-pounder to the modern 110-ton breech-loading gun; the introduction and increase in thickness of armour-plates, from the 4 inches of the "Warrior" to the 24 inches of the "Inflexible," and the thick iron armour, with a steel

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[1] Minutes of Proceedings Inst. C.E., vol. xxii., pp. 5, 130.

face, of the most recent ships; the general adoption of steel for shipbuilding and other purposes: all these things, and many more, came within the range of Mr. Samuda's experience.

Mr. Samuda was among those who, in 1860, co-operated with Sir Edward Reed, M. Inst. C.E., in the formation and establishment of the Institution of Naval Architects, of which he was elected the original treasurer, and a member of council. He subsequently became one of its vice-presidents. In the progress of that Institution he naturally took a great interest, and was a regular attendant at its meetings. His contributions to its Transactions were numerous, and there were few discussions of any importance in which his voice was not heard and listened to with the greatest deference. He was universally regarded by the members of that Institution as one of its most zealous leaders, and most able debaters. Mr. Samuda was a member of an important Committee appointed by the Admiralty last year, and presided over by the Earl of Ravensworth, to inquire into the condition under which contracts are invited for the building and repairing of H.M. ships, and their engines, and into the practical working of H.M. dockyards.

Mr. Samuda took his seat in Parliament as Member for Tavistock, in the year 1865, on the Liberal side of the House, which seat he retained until the dissolution in 1868. In that year he was returned as Member for the Tower Hamlets, for which constituency he was re-elected in 1874. He continued to represent it until the election of 1880, when his constituents refused to return him on account of his attitude towards the foreign policy of the out-going Government. He spoke frequently in the House, and his speeches were always regarded as valuable contributions to the subject under discussion, more especially when the subject happened to be the navy or kindred branches of the public service.

He died somewhat suddenly on Monday, April 27th, 1885, from syncope, and was buried, May 2nd, in Kensal Green Cemetery. His long and honourable life, his widely extended business relations, his close connection with scientific institutions, and his position as Member of Parliament, had made him known to a large circle of friends, by whom the news of his death was received with the deepest regret.

ALAN CHARLES BAGOT, second son of Colonel Charles Bagot, Grenadier Guards, and Assistant Master of the Ceremonies to the Queen, was born at Elford, near Tamworth, on the 1st of June 1856. He died at Bournemouth on the 22nd of April, 1885, of con-

sumption, induced by an accident in a mine more than four years previously, aggravated by subsequent hard work and exposure.

Alan Bagot was educated at Eton, and at Pembroke College, Cambridge. He very early showed a love of Natural Science, and exhibited considerable inventive power. He was demonstrator of chemistry at the laboratories of Eton and of Cambridge, and was engaged before he left the University in special experiments for the late Mr. John Taylor, M. Inst. C.E., of Earsdon, to whom he was articled in 1873. At nineteen he patented a safety-indicator for mines, which was adopted in the mines of the Duke of Sutherland, Lord Dudley, and others; the invention being equally applicable to guard against spontaneous combustion in ship-cargoes. In 1876 Mr. Bagot was engaged experimenting on spontaneous combustion in coal, cotton, and wool, and invented an electric detector that has been awarded several medals, and the first order of merit at the Melbourne Exhibition in 1881. In 1877 he became chief Electrical Engineer to the firm of Messrs. Apps and Co., London. His attention was soon engrossed by the earnest wish to save life in mines, and the prevention of the deplorable accidents caused by ignorance and carelessness. The substitution of self-extinguishing safety-lamps,[1] instead of the old-fashioned Davy and Clanny lamps, and the increased care and efficiency in the lamp-rooms in collieries, are largely due to his investigations, and to his exertions in the cause of saving miners' lives. He possessed two Gold Medals for saving life at his own personal risk. He brought out many improvements in electrical apparatus, amongst them being a portable set of resistance coils for use on railways and for torpedo-work. He also introduced a block system of electric signalling that has been well-spoken of, and in 1883 an automatic electric transmitter.

He was the author of several scientific papers and books: "Accidents in Mines," "The Principles of Colliery Ventilation," "The Application of Electricity to Mines," &c., and the recently-published "Principles of Civil Engineering as applied to Agriculture and Estate Management," written during great suffering and advanced disease. This was produced when he could have no access to books of reference or his own papers, and he was dissatisfied with it. Mr. Bagot was in 1880 appointed Consulting Engineer to the Trent Board of Conservators, on account of his special knowledge of the pollution of rivers, and he published a pamphlet on "The Prevention of Floods." Under his guidance the Trent Fishery-District became one of the best organized in England,

[1] Institution of Mechanical Engineers. Proceedings. April 1879.

a service feelingly acknowledged at Quarter Sessions by the Lord Lieutenant, upon Mr. Bagot's enforced resignation from illness.

Alan Bagot was buried at Blithfield, Staffordshire, where he had passed much time in boyhood and youth. When the body arrived from Bournemouth at the Trent Valley station, numbers of miners and working-men came to show respect, saying they had lost their best friend. He was a bright, clever man, and, before illness had incapacitated him, of a most cheery disposition. He set an excellent example to men of his own age, being a very hard worker, thorough in what he did, and a gentleman in every sense of the word.

He was elected an Associate Member of the Institution on the 2nd of May, 1882; he was also a certificated Mining Engineer, a Fellow of the Chemical Society, and a Member of the Society of Arts.

DAVID MANUEL was educated in Edinburgh, where he was well known and much esteemed. He studied engineering under the late Professor Fleeming Jenkin, M. Inst. C.E., at the Edinburgh University, and was for many years in the office of Messrs. J. & A. Leslie, during which time he had charge of various important works, including the relaying of the Hawick Waterworks, the building of the new iron bridge across the Whitadder near Berwick-on-Tweed, the introduction of the new drainage and water-supply at Lerwick, and the construction of a timber steamboat-pier at Easdale for the Earl of Breadalbane. He left Edinburgh in September, 1873, to fulfil an engagement with Messrs. Glover and Co., railway-contractors, India, and was one of their agents in the construction of the railway from Agra to Jeypore until the end of 1876, when he received an appointment as assistant engineer on the East Indian Railway at Howrah, Bengal. Here he was engaged on several important works, amongst which may be named the reconstruction of the goods station at Howrah, including the erection of extensive grain-storage, and of a viaduct for road-traffic over the Howrah station and goods-yard, which viaduct cost £25,000. It is 2,100 feet in length, the ironwork weighing upwards of 700 tons, measuring 1,300 feet, and each of the masonry approaches 400 feet. In the beginning of 1882 Mr. Manuel was promoted to the grade of chief resident engineer at the Hooghly Bridge Works, Bengal. The bridge, which will be one of the finest in India, is the first fixed bridge erected across the Hooghly, and will complete the line of railway into Calcutta. Its construction is, like that of the

new Forth Bridge, on the cantilever principle. There are two side spans, each of 540 feet, and a central span of 120 feet, in three girders, the centre cantilever girder, 360 feet long, resting on a double pier sunk in the bed of the river; the two side girders are each 420 feet long. It is estimated to cost £355,000. While residing at the Hooghly Bridge Works during the arduous and anxious labour of sinking the caissons of the central pier, and consequent exposure to the malarious influence of the climate, he was struck down by an attack of fever and dysentery, and was sent by his medical advisers on a voyage to Australia to recruit his health. But it was too late, the disease terminated in abscess of the liver, of which he died at Adelaide, South Australia, on the 7th of February, 1885—thus adding another to the many Civil Engineers who have fallen as the result of devotion to duty, which impels them day after day to overtax their strength in an exhausting climate, until the frame has not the power to resist the malarious poison.

In undertakings committed to his care Mr. Manuel discharged his duties with a skill and thoroughness which gave the utmost satisfaction to all concerned, and won for himself many warm friends. Mr. Manuel was elected an Associate Member on the 4th of December, 1877.

Major AMBROSE AWDRY, R.E., was born on the 28th of April, 1844. He was a son of the late Sir John Wither Awdry, Chief Judge of the Supreme Court of Bombay from 1839 to 1842, and a grandson of the late Bishop Carr, of Bombay. After being educated at Cheltenham college, and at the Royal Military Academy at Woolwich, he obtained a commission in the Corps of Royal Engineers, on the 9th of December, 1864, and continued his engineering education at the School of Military Engineering at Chatham. In 1867 he was employed on the construction of the Fort at the Castle Hill at Dover, now called Fort Burgoyne. On the 15th of January, 1868, he was appointed an assistant engineer in the Bombay Public Works Department—his family connections having led to the selection of that Presidency as the sphere of his employment—and was posted to the Scinde Division, where he had charge of the Buildings and Roads in a large district and two military stations, and rose to the departmental rank of Executive Engineer, Fourth Grade, on the 1st October, 1871. While in Scinde he had the opportunity of gaining some experience in canal- and railway-work; and that he took an intelligent interest in the harbour-works then in progress at Kurrachee was shown later on.

In May 1872, he was ordered to the Madras Presidency as Military Secretary to the late Vere Henry, Lord Hobart, whose wife was his mother's sister, and who just then became Governor of Madras, and from this appointment he was transferred to the Private Secretaryship in March, 1873. In both capacities he secured the respect and esteem of all who had business relations with him, as their medium of intercourse with the Governor, performing the duties of both situations with tact and courtesy. His favourable opinion of the manner in which the Kurrachee Harbour Works had been carried out had much influence in determining Lord Hobart to support the design for a harbour at Madras, prepared by Mr. William Parkes, M. Inst. C.E., the Consulting Engineer of the Kurrachee Works, and which design is now in progress of execution.

On Lord Hobart's sudden death at Madras, on the 27th of April, 1875, Lieutenant Awdry reverted to professional employment as Executive Engineer, Third Grade, in the Madras Public Works Department, and carried on the Road, Building and Irrigation Works, in the Coimbatore District till December 1879. During this period he did excellent work in the sad famine years of 1876-78, commending himself to Government as an officer on whom reliance could be placed for strict performance of any duty entrusted to him. He was elected an Associate of the Institution on the 4th of December, 1877, and on the 6th of February, 1878, he obtained promotion to be Captain in the Army.

In December 1879, he was transferred as Superintendent of Works, to the Buckingham Canal on the East Coast of Madras, obtaining departmental promotion to Executive Engineer, Second Grade, on the 1st of June, 1880. By April, 1881, he had well earned a two years' furlough to England; but the 5th of November following found him back again at Madras, having been preferred to his old post of Private Secretary, by the Right Honourable M. E. Grant Duff, the new Governor. It is almost needless to say that his previous experience of the duties of this post, and the discretion with which he performed them, rendered his services peculiarly valuable to the new Governor, as they were grateful to all with whom they brought him in contact.

The two officers of his corps, who officiated as Chief Engineers and Secretaries to Government in the Department of Public Works, during the two periods of his service in this important position, have both recorded their appreciation of his loyal co-operation, whenever he was in a position to further their views on engineering matters, and for the good of the department. The end of twenty years' service saw Captain Awdry's promotion to Major on the

9th of December, 1884, and found him in a public position of much promise; so that his sudden death was felt as a calamity, not only by his own family, but by a large circle of attached and admiring friends. It resulted from his horse falling with and on him, when out hunting on the Neilgherry Hills, causing fatal rupture of internal organs, mortification whereof carried him off in a few days, on the 18th of May, 1885, after much suffering.

JOHN DUNNING, the youngest of a family of seven children, was the son of a farmer of Fadmoor, near Kirby Moorside, the members of the family having for several generations lived and died on the Feversham Estate. He was born in the year 1826, and his father dying soon afterwards, the widow sold her farm and migrated with her family to the city of York, where John Dunning spent his early childhood. In his tenth year he was sent to the Quaker school at Ackworth, near Pontefract. When John Dunning was sixteen or seventeen years of age, a brother took the Thorpe Corn Mills, four miles from Stockton; and this brought to Tees-side the man who was destined to become one of the leading spirits in guiding the destinies of the new and rising town of Middlesbrough. He remained at the Thorpe Mills till the year 1845, when he entered the office of the owners of the Middlesbrough Estate, and was placed under Mr. Isaac Sharpe, the well-known Friends' missionary, who was at that time the principal agent of the Middlesbrough Estate. It was to the late Mr. Joseph Pease—who was ever on the look-out for energy and ability in a young man—that he owed the latter position. He passed a period of initiation in Darlington, after which he was sent back to Middlesbrough to act as check-clerk, or auditor, over the accounts at the brickyards and wharves. Hear he plodded on year by year, receiving further promotion and larger emolument as time went on. He was remarkably active, not only in his business, but in the political and social sphere, and was well known throughout the district for his ardent advocacy of the temperance cause. In time he became agent of the Middlesbrough Owners, in the place of Mr. Sharpe, and he was also, in 1847, appointed to the secretaryship of the Middlesbrough Gas Company, then a private concern. He was appointed borough surveyor of Middlesbrough in 1855, an office which he held for fourteen years. In 1868 the firm of Jones, Dunning, and Co., whose works are known as the Normanby Ironworks at Cargo Fleet, was started, the subject of this notice being one of the partners. On ceasing to be the Borough Surveyor Mr. Dunning became a candidate for the Town

Council, and after several severe contests was elected in 1872 for the Middle Ward. From the time of entering the Council, Mr. Dunning, who, from his somewhat stubborn and unyielding temperament, had enemies, had to fight his way upwards against considerable opposition. In time, however, he made himself felt in the municipal councils, and in 1875 he was elected to fill the civic chair, his predecessor having been Mr. T. Hugh Bell. In 1877 he was promoted to the aldermanic bench, where he continued to hold his seat until his death.

Mr. Dunning was a man of strong opinions, which he tenaciously maintained, and his life was consequently one long battle. One who knew him well writes, that "any one contending with John Dunning found in him a strong and bitter, but still a frank and open enemy, ready after a contest to shake hands with his opponent. In spite of apparent arrogance and self-will, no man could be more true and tender towards those who sought any favour at his hands, and his kind and thoughtful charities were distributed with no niggardly hand." As an instance of the kindliness of his disposition may be mentioned his connection with the "War-Victims Fund," provided at the end of the great struggle of 1870–71 to provide relief for the sufferers who had taken no part in the war. Mr. Dunning and his associates were, after the battles around Metz, much impressed with the conviction that the best thing they could do to help to restore the desolated district was to send out a steam plough, and to sow the land with English seed-corn. For some time there was considerable difficulty in finding any one willing to undertake the mission, when at last Mr. Dunning was induced to take charge of the work. He went out in December, 1870, and spent Christmas in France, along with Mr. Thomas Snowdon (late of the firm of Snowdon and Hopkins, Middlesbrough), and Mr. Joseph, of Louth, Lincolnshire. In the result the operations of this kind were extended till July of the following year, and were instrumental in averting much misery, which must have resulted from the inability of the tillers of the soil to sow their corn.

Mr. Dunning died on the 5th of March, 1885, in his fifty-ninth year. He was a man of healthy and robust appearance, and, previous to the illness which terminated fatally, might have been supposed to have many years of life before him. He was elected an Associate of the Institution on the 6th of December, 1865.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Experiments on the Crushing Strength of Brickwork.

By G. SACHERI.

(L'Ingegneria Civile, 1885, p. 1.)

These experiments were made upon blocks of brickwork of three sizes (A) 0·35 metre (1 foot 2 inches), (B) 0·46 metre (1 foot 6 inches), and (C) 0·64 metre (2 feet 1 inch) square respectively. In each case the height of the block was six courses. A slab of stone was placed above and below each block in order to distribute the pressure. The testing machine was capable of working up to 750 atmospheres; the diameter of the cylinder was 376 millimetres (14·80 inches). The bricks were those commonly used as the best in Turin, not specially made. When tested singly the breaking-weight of four samples varied from 360 to 500 lbs. per square inch for the first crack, and 1,777 to 2,225 lbs. for complete fracture, the means being 432 and 2,053 lbs. per square inch, whereas the crushing-strain of special bricks reaches 2,844, and in very exceptional cases 4,863 lbs. The mortar was made of lime from Casale. Eleven months were allowed for the brickwork to set. Half bricks were used in blocks B and C. The mortar was from 0·27 inch to 0·4 inch thick, and proved to be stronger than the bricks. Two ½-inch boards were placed above and below the brick blocks when placed in the press. The first block experimented on was one of the largest size (C). The bricks of which it was built were burnt in a continuous kiln. The first, scarcely perceptible, crack occurred at one corner under a pressure of 1,151 lbs. per square inch. At 1,250 lbs. vertical cracks began to appear at a distance of 7 inches from the same corner. At 1,459 lbs. the cracks became numerous and extended half through the blocks. At this time the stone slabs began to split. At 1,635 lbs. the block may be said to have been completely crushed, and on the pressure being removed it was found that the inside was reduced to a mass of powder.

The second block was of the same size, the only difference being that the bricks had been burnt with wood in an old-fashioned non-continuous kiln. A layer of cement was spread between the wooden slabs and the faces of the press, and when the experiment was finished it was found that the cement had not been spread

evenly, and this accounted for the block giving way sooner than was expected. The first crack appeared at a pressure of 540 lbs. per square inch. At 1,113 lbs. there were cracks all over the block. The experiment was not continued further, as it was not intended to completely crush this block. The other experiments are described in detail, and the results are summarised in the following Table:—

—	Pressure in lbs. per Square Inch at which took place—			
	The First Crack in the Brickwork.	The First Crack in the Stones.	Cracks and Fissures on all the Faces.	Complete Crushing.
Single bricks (mean) . . .	432	..	..	2,053
1st. A block (1 ft. 2 in. square)	806	921	921	..
2nd. A " (" ")	576	No cracks	921	..
Mean	691		921	
1st. B block (1 ft. 6 in. square)	711	924	1,257	..
2nd. B " (" ")	711	711	1,038	..
Mean	711		1,147	
1st. C block (2 ft. 1 in. square)	1,151	1,459	1,459	1,635
2nd. C " (" ")	537	537	1,113	..
Mean	844		1,286	

The Author makes the following remarks upon the experiments:—

1st. That complete rupture requires a far higher pressure than the first crack.

2nd. That the first crack is frequently due to a local cause, and that the third column is a better test than the first of the strength of the blocks.

3rd. That in every case the first crack occurred within about 4 inches of a corner; that the bricks always gave way before the mortar; the direction of the cracks was generally vertical.

4th. That bond stones are not much use.

5th. It appears from the third column that the resistance per unit of sectional area is higher in the larger blocks than in the smaller.

6th. Though the increase of pressure was applied slowly and a period of rest was allowed after each increment of 10 tons, still the conditions were very different from those of dead weight.

7th. The conditions differ from those of practice in that the mortar was allowed eleven months for setting before being subjected to pressure, instead of the weight being gradually applied while the mortar was still green.

8th. It is much to be desired that similar experiments should be made with harder bricks.

Reference is made to the experiments referred to in the Minutes of Proceedings, vol. lxxiii., p. 385.

W. H. T.

Report of the General Meeting of German Cement Manufacturers.

February, 1884.[1]

As at the previous meeting, the subject of the admixture of Portland cement with less valuable materials absorbed the chief share of attention.[2] Dr. Delbrück, the president, was able to announce that the question had attracted so much notice amongst cement-users, that a wide spread mistrust had arisen with respect to cements with foreign admixtures. The results of experiments on the behaviour of pure and mixed cements were reported to the meeting by Dr. Böhme of Berlin, and R. Dyckerhoff of Amöneburg. The former gentleman stated that he had never, in the course of his numerous investigations, found the tensile strength of a mixed cement greater than that of the same material in a pure state, and further that, in testing cement under compression and tension, the equation of the crushing-strain divided by the tensile strain invariably gave a smaller quotient for the mixed than for pure materials.

These facts were fully borne out by the comprehensive experiments of R. Dyckerhoff. These are brought together in the three following Tables, which show conclusively the influence of various finely pulverized substances upon the strength of Portland cement, tested at various dates:—

TABLE I.

Sample A (set in 9 hours).		Tensile Strength in lbs. per square inch in		
		4 weeks.	26 weeks.	52 weeks.
100 parts of cement	+ 300 parts sand	301·5	392·4	442·3
80 ,, ,, 20 ,, pulverised slag	,, ,,	263·0	348·4	379·7
80 ,, cement 20 ,, trass	,, ,,	270·2	322·8	429·4
80 ,, cement 20 ,, ground limestone	,, ,,	237·5	321·4	358·3
80 ,, cement 20 ,, slaked lime	,, ,,	220·4	327·1	349·8

[1] The original is in the library of the Inst. C.E.
[2] Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 386.

TABLE II.

Sample B (set in 7 hours).	Tensile Strength in lbs. per square inch in 4 weeks.	13 weeks.	26 weeks.
100 parts of cement + 300 parts sand	295·8	348·4	385·4
90 ,, ,, / 10 ,, pulverised slag ,, ,,	261·6	324·2	348·4
90 ,, cement / 10 ,, fine sand ,, ,,	258·8	300·0	378·2
90 ,, cement / 10 ,, ground limestone ,, ,,	258·8	312·8	375·4
90 ,, cement / 10 ,, slaked lime ,, ,,	270·2	310·0	376·8
80 ,, cement / 20 ,, pulverised slag ,, ,,	219·0	274·4	324·2
80 ,, cement / 20 ,, fine sand ,, ,,	223·2	280·1	351·2
80 ,, cement / 20 ,, ground limestone ,, ,,	228·9	274·4	351·2
80 ,, cement / 20 ,, slaked lime ,, ,,	214·7	274·4	337·0
67 ,, cement / 33 ,, pulverised slag ,, ,,	192·0	230·4	290·1
67 ,, cement / 33 ,, fine sand ,, ,,	197·6	251·7	310·0
67 ,, cement / 33 ,, ground limestone ,, ,,	193·4	248·9	307·1
67 ,, cement / 33 ,, slaked lime ,, ,,	145·0	206·2	265·9

TABLE III.

Sample C (set in 14 hours).	Tensile Strength in lbs. per square inch in 4 weeks.	13 weeks.	26 weeks.
100 parts of cement + 300 parts sand	297·2	348·4	391·0
90 ,, ,, / 10 ,, pulverised slag ,, ,,	287·2	325·6	375·4
90 ,, cement / 10 ,, fine sand ,, ,,	263·0	342·7	378·2
90 ,, cement / 10 ,, ground limestone ,, ,,	284·4	344·1	371·1
90 ,, cement / 10 ,, slaked lime ,, ,,	275·8	321·4	349·8
80 ,, cement / 20 ,, pulverised slag ,, ,,	233·2	292·9	318·5
80 ,, cement / 20 ,, fine sand ,, ,,	227·5	329·9	335·6
80 ,, cement / 20 ,, ground limestone ,, ,,	240·3	284·4	322·8
80 ,, cement / 20 ,, slaked lime ,, ,,	243·2	294·3	314·2
67 ,, cement / 33 ,, pulverised slag ,, ,,	204·8	273·0	277·3
67 ,, cement / 33 ,, fine sand ,, ,,	207·6	283·0	305·7
67 ,, cement / 33 ,, ground limestone ,, ,,	210·4	255·9	270·2
67 ,, cement / 33 ,, slaked lime ,, ,,	169·2	228·9	257·4

It follows from the above Tables that powdered slag has no better effect upon the cement than the addition of an equal volume of sand. Indeed, if the sand is carefully selected, it is possible to obtain higher tests with it than with slag. The foregoing experiments deal only with the tensile strength of the various mixtures, but in Table IV., parallel tests are given of the resistance both to tension and compression.

TABLE IV.—BEHAVIOUR of PURE and ADULTERATED CEMENTS MADE UP INTO MORTAR with the ADDITION of LIME.

Nature of Cement used.	Normal Test (3 parts of sand).	Cement, lime, mortar. 1 cement; 6 sand; 0·5 lime.		Nature of Mixture.	Specific Gravity.
		Tensile strength in 28 days.	Crushing strength.		
A pure cement . .	319·9	177·7	3981·6	None . . .	3·170
B ,, ,, . .	310·0	167·8	3483·9	,, . . .	3·129
C ,, ,, . .	223·2	128·0	2784·3	,, . . .	3·168
D ,, ,, . .	257·4	157·8	3014·6	,, . . .	3·119
D 1 mixed	189·1	89·6	1763·3	Lime . . .	3·027
E ,, ...	221·8	81·0	1777·5	Silicate of lime	3·072
E 1 ,, ...	193·4	65·4	1734·8	,, ,,	3·067
F ,, ...	176·3	69·7	1478·9	Lime . . .	3·090

With reference to the estimation, qualitatively and quantitatively, of foreign admixtures known to be present in Portland cement, great progress has been made during the past year, and it has become possible to ascertain by means of qualitative analysis with comparative ease the presence of all the known substances employed for adulteration, though the like amount of perfection has not been arrived at in the quantitative analysis of adulterated cements.

The most thorough investigation in this connection has been conducted by Professor Fresenius of Wiesbaden, who examined for the association twelve samples of unmixed cement, obtained from Germany, England, and France, three samples of hydraulic lime, three samples of slag, reduced to a powdered condition by atmospheric action, and three samples of ground slag. Some of the more interesting facts arising from the researches of Dr. Fresenius could not be published at the meeting, as he reserved to himself the right of making them known hereafter, but the general results are set forth in the Tables published in the Minutes of Proceedings, vol. lxxix., p. 377.

G. R. R.

On Natural and Artificial Portland Cements. By G. Leven.

(Ingener, St. Petersburg, February, 1885.)

The Author commences by stating that although the use of Portland cement in Russia is extending year by year, yet the imperfect knowledge which exists, concerning its nature and properties, acts as a hindrance to the development of cement manufacture as a national industry.

The chief point on which ignorance prevails is the question as to the difference between natural and artificial cements, and he proceeds to explain that Roman cement is distinguished by the irregularity of its chemical constitution and its cheapness of production, almost exclusively, from natural stone, whereas Portland cement is a strictly definite chemical combination of from thirty-one to thirty-four parts alumina and silicic acid, and sixty-one to sixty-four parts of lime, and is produced at a temperature nearly double that required in the manufacture of Roman cement. Upon the exact proportion of the ingredients depends the setting qualities of cement, and variations within very narrow limits produce an important effect on its quality. The specific gravity of Portland cement is always higher than 3·1, that of Roman lower than 3·0.

Portland cement is generally made out of an artificial mixture of the substances entering into its constitution, but there is a limestone of the tertiary formation which is composed of all the ingredients in proper proportion, and forms a natural cement stone.

The prevailing idea is that natural cement means Roman cement, and is inferior to Portland or artificial; this idea is wholly erroneous because the natural Portland cements are of very high quality. Witness the municipal works of Vienna, the harbour works of Trieste, the St. Gothard Railway, and other important constructions. At Novorossisk (South Russia) a factory has been established producing, from natural rock, cement of very high quality which has been thoroughly tested by the Ministry of Ways of Communication, as well as in the building of the bridge across the Dnieper at Ekaterinoslav, and in the harbour works at Sevastopol and Batum. It is important that constructors should clearly understand that natural Portland cements are of the highest quality, and those made in Russia are even superior to the best foreign artificial productions.

W. A.

The Action of certain Admixtures upon Portland Cement. By Professor L. Tetmajer, of Zurich.

(Schweizerischer Bauzeitung, No. 24, 1884.)

After acknowledging the services rendered by the German cement-makers in the position they have taken up with respect to

adulteration,[1] and the value of the investigations of Professor R. Fresenius, of Wiesbaden,[2] the Author points out that his own experiments concerning the action of certain admixtures upon cement do not coincide with the results obtained by Mr. R. Dyckerhoff.[3] He states that his researches were undertaken with a view of learning something concerning the subject, and not in order to prove any particular theory. The influence of foreign ingredients upon Portland cement depends upon two sets of operations which must be kept distinct; the one set being wholly of a physico-mechanical nature, the other involving a chemical re-arrangement of the molecules. Both actions may result in an increase in the normal tensile strength of the mortar. The increase of strength in the mortar tests, due to the admixture of various inert, and for the most part specifically lighter substances, as for instance, finely ground limestone, rests solely upon a reduction of the injurious effects of the volumetric increase, which freshly-ground cements always undergo in a greater or less degree. Possibly, moreover, in the case of certain cements an increase is caused by this means in the superficial area of the binding agent (*Kittsubstanz*), and, therefore, an increase also in the density. It can be proved by means of the addition of slaked lime, or lime putty, to cement that the eventual augmentation of the tensile strength in the sand test thereby obtained is in no way caused by a chemical molecular change due to the addition of such inert substances.

But the facts are wholly different when the Portland cement is mixed with certain finely ground ingredients containing silicic acid in a state adapted for chemical combination.

Under such conditions a chemical action is set up, whereby not only the tensile strength of the pure cement mortar, but also that of the equivalent mixture of cement with lime is frequently increased in a surprising degree. From the results obtained by former experimenters there is little room for doubt that when an improvement in Portland cement is brought about by the addition of soluble silica this can only be attributed to the formation in the first instance of colloidal hydro-silicates of lime, the cement itself furnishing the lime needed for the formation of hydro-silicates. It is now pretty generally admitted that Portland cement liberates lime during the first stages of its induration. In proof of this the Author states that he has found on large cubes of concrete, made of highly calcined Portland cement, having a specific gravity of 3·1 to 3·2, an efflorescent growth of carbonate of lime, and in the case of a bridge of Portland cement concrete, made for exhibition by Mr. R. Vigier, while on the abutments, consisting of a mixture of river sand, screened ballast and Portland, there were abundant evidences of the formation of carbonates, on the arch, which was composed of a mixture of Portland cement and granulated blast-

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii, p. 386.
[2] *Ibid.*, vol. lxxix., p. 377.
[3] *Ante*, p. 346.

furnace slag, no signs of the formation of stalagmites, or carbonates could be observed. This later fact is further important as indicating the influence of slag upon cement in works on a large scale. Free lime in the Portland cement, and silicic acid, in a state free to combine, in the added materials, are the essentials and the deciding conditions in the much-talked-of adulteration question.

Guided by his experiments, the Author maintains that when, on the addition of foreign ingredients, no diminution takes place in the tensile strength of the briquettes of the mixed material, as compared with those made from the pure cement, with and without the addition of lime, the cement has been improved by such addition. There can, of course, be no question that such improvement has been effected when the tensile strength of the mixed cement, alone and with lime, is increased to a marked extent.

The action of foreign ingredients upon Portland was examined by the Author, with four different substances, and five varieties of cement which were tested at various ages. The tests included also an investigation concerning the influence of the use of more or less water, and greater or less ramming into the moulds. The substances employed for admixture were, first, pure blast furnace slag; second, a composite slag, and third and fourth, mixtures specially rich in active silicic acid. Trials were first made of the tensile strength of the slags, granulated, and not granulated, mixed only with lime, in order to study the power they possessed of forming silicates, and indurating in the manner of hydraulic limes. In some cases a tensile strength of 23·5 kilograms per square centimetre was thus reached in 28 days. Analyses of the slags and cements are given, and a tabulated statement of breaking weights of a series of mixtures and pure cements follows; a large proportion of samples in which 85 parts of cement, 15 parts of slag, and 300 parts of sand were tested, show a tensile strength considerably in excess of that attained by a mixture of one hundred parts of the pure cement with three hundred parts of sand.

G. R. R.

Buildings of Concrete (Lime and Cement). By — Kerbeds.

(Ingener, Moscow, April 1885, p. 181.)

An effort is being made to increase the more general adoption of this form of building in Russia, to which end the Author, Mr. Kerbeds, the engineer of the new canal from Cronstadt to St. Petersburg, has recently issued a useful treatise on the subject, in which he says that this method of building came into more general use, on any considerable scale, at the beginning of the present century, in Sweden, afterwards in Germany, and is now practised to some extent in Russia, and with a view to its more general adoption, especially for the poorer class of houses, for which it is considered particularly suitable, a concise yet minute description

of all the details of building construction by this method is given, supplemented by numerous sketches and particulars, the whole being written in such a way that these erections may be undertaken even by unskilled labour.

The Author is convinced that from its comparative simplicity, non-combustible nature, and substantial appearance, together with the low cost for materials and labour required, warrants the more general adoption as a form of building for Russia, which, as a consequence of diffusion of the knowledge of designing and constructing, selection of suitable materials, &c., he believes it will receive.

Full particulars are given, describing the methods of constructing walls, the materials required, and their composition, lime, sand, mortar, and cement mixtures, supplemented by directions for the construction of wood casings, boxes, &c., to be used during erection of walls, corners, inner cross-walls, recesses, &c.; also describing the method of constructing foundations, chimneys, windows, doorways, floors, ceilings, &c., concluding with the necessary suggestions as to procedure during the whole process of building. The Author considers the cost of a cube 7 feet square of such a monolith structure, of walls of lime and sand, as an average 56*s.*, that is, 7 square feet of such a wall, 14 inches thick, costs 14*s.*, or with a better class of work, adding a proportion of cement, about 21*s.*, including the cost of building-cases, rammers, scaffolding, &c.

W. W.

Cinders used in Construction.

(Le Génie Civil, vol. vii., 1885, p. 10, 2 woodcuts.)

For many years the cinders left by the combustion of coal used to accumulate at Lyons as a useless residue round the manufactories, and formed an encumbrance in private houses. At last it occurred to some builders, wishing to erect some buildings with several floors, at a moderate cost, to utilize this refuse. By mixing the cinders with a little lime, a material was formed with sufficient cohesion to bear a flooring in a few days, and, when constructed as an arch, to have its centering removed a month after it was dry. This sort of masonry could be constructed, at first, for three shillings a cubic yard, owing to the abundance of cinders; but now the cinders at Lyons, after thirty years' experience of their value for this purpose, are so fully utilized that large quantities have to be brought from a distance, and the price has risen to about 6*s.* 8*d.* per cubic yard. The proportions usually adopted are four parts of cinders to one part of lime. The arches of this material are constructed like those of concrete, except that the punning is effected in a direction tangential to the extrados; and they are given a thickness of from $1\frac{1}{6}$ to $1\frac{1}{3}$ foot, at the crown for a span of $16\frac{1}{2}$ feet. Within the last two or three years this material has

been used for portions of important buildings. The arches forming the basement of the Prefecture at Lyons have been quite recently constructed with slag and lime. A trial arch of 21 feet span and only 4 feet rise, and a thickness of 1½ feet at the crown increasing to 3 feet at the haunches, was loaded with a distributed weight of rather over 2 tons to the square yard, and did not show the slightest sign of injury. A block of stone, weighing about 12 cwt., was then dropped on the crown of the unloaded arch from a height of 3¼ feet, and did not affect it. It was also found to bear fire without being weakened. This material also possesses the advantage of lightness, as it only weighs 2080 lbs. per cubic yard, or more than a third less than rubble masonry.

L. V. H.

Comparative Experiments on the Welding of Steel and Wrought Iron. By J. Bauschinger.

(Mittheilungen aus dem mechanisch-technischen Laboratorium der k. Technischen Hochschule in München, No. 12, 1885, p. 31.)

These experiments were undertaken by the Author at the instance of an engineering firm.

Similar experiments had been previously made at the Royal Mechanical-Technical Experimental Institute at Berlin,[1] and by Mr. W. Hupfeld, at Prevali,[2] which gave very different results; those at Berlin being very unfavourable, those at Prevali very favourable, as regards the welding capacity of steel (*Flusseisen*). The Author recapitulates the main results of these tests before describing those made by himself. The materials used in the latter were steel (*Flusseisen*), from the "Peine" ironworks at Hanover, and bar-iron of various sections from the "Neuhoffnungshuette" near Herbauer, in Nassau.

The test-pieces were flat, square, and round, in section, the largest being 80 × 30 millimetres (3·149 × 1·181 inch). Each piece was cut in two cold, swelled up on the anvil when hot, five to ten millimetres (0·196 to 0·392 inch), and put into the form shown in Figs. 1 and 2, and, after heating to the proper degree, the two portions were laid on each other (as shown), and welded together by hand- or steam-hammer.

Some preliminary studies were made in the laboratory of the college to ascertain the best method of welding, and the best flux for steel; quartz sand answered the latter purpose, while it was found that a rather less degree of heat was required for steel than for wrought-iron; a pure coal fire was used.

In the chief experiments, the steam-hammer was employed. Every piece after welding was tested in the usual way for tensile

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[1] "Verhandlungen des Vereins zur Befoerderung des Gewerbefleisses in Preussen," 1883, p. 146.

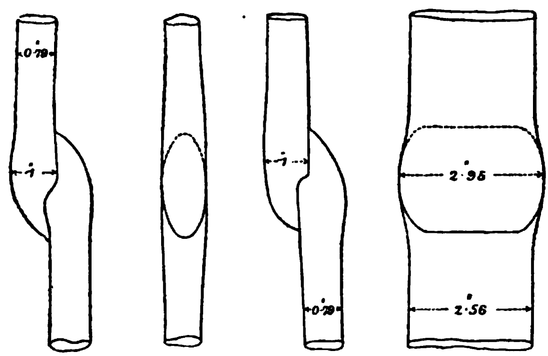
[2] "Oesterreischen Zeitschrift für Berg- und Hutten-wesen," No. 8, 1884.

strength; the limit of elasticity, contraction, extension, and ultimate strength being determined, the same quantities having been measured for pieces of exactly similar quality, section, and length, but without a weld.

The results are given in a tabular form. Both for steel and iron the limit of elasticity is nearly always reduced by welding, and this is, without exception, the case as regards the extension, the contraction of welded is less than that of unwelded pieces when the fracture takes place in the welded portion.

The general conclusions arrived at are, that for steel, the best welding temperature is just at the transition from a red to a white heat, a quick fire and smart handling are necessary, as the piece should not be long in the fire.

Fig. 1. Fig. 2.



Analyses were made of three samples, one of which welded admirably, the second badly, and the third not at all.

The Author is of opinion that in the case of mild steels, such as those tested, with a low carbon, intended to take the place of bar-iron, success or otherwise in welding depends less on the chemical composition than on the mechanical treatment.

G. R. B.

Framed Girders with Double Bracing Statically Determined.

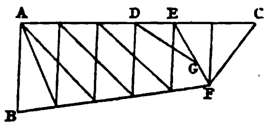
By R. Krohn.

(Zeitschrift des Vereines deutscher Ingenieure, 1885, p. 435.)

The cantilever A B C is fixed at A and B. On account of the double bracing the system is statically indeterminate with the usual arrangement of diagonals. It is, however, possible to make it determinate by putting in a short member F G and joining the last two diagonals D G, E G at G. The system is then seen to be statically determinate and stable in all its parts. Taking C as the

starting point the diagram of forces may be drawn, and on the other hand the geometrical form of the girder may be simply constructed starting from A and B from the lengths of the individual rods. The distribution of the strains upon the two systems of framing may be regulated by altering the position of the point G. It is desirable that the strains caused by the weights operating at C and F should be so divided between the diagonals D G and E G that the vertical components of the strains in them may be equal.

FIG.



By a similar arrangement a girder with double bracing, supported at both ends, may be rendered statically determinate, but the introduction of the short member F G is not so satisfactory in this case. For cantilevers, however, such as occur in bridge systems with free points of support this arrangement is very advisable, as in such cases the chief part of the strain comes from the loading of the free end C, and it is possible to distribute the weight equally upon the two systems of diagonals. Moreover in construction it is an advantage to have the one member F G at the point F instead of two diagonals, as the joint is thus simplified. This arrangement has been used by Schneider in the new Niagara bridge.

W. B. W.

Lift-Bridge on the Ourcq Canal. By G. CERBELAND.

(Le Génie Civil, vol. vii., 1885, p. 1, 1 plate and 3 woodcuts.)

A branch railway crosses the Ourcq canal connecting the cattle station of La Vilette at Paris with the main line. Owing to the small difference of only 1 foot 1½ inch, between the highest water-level of the canal and the level of the rails, which it was inexpedient to raise much, an ordinary swing-bridge was not suitable for spanning the canal, which required a clear waterway of 26¼ feet. An ordinary iron girder bridge was accordingly designed which is lifted 16½ feet above the water-level of the canal by four chains attached at the four corners and passing over pulleys, and each carrying a counterbalancing weight of 5 tons, suspended at its further extremity. The bridge is kept lifted, except when required for the passage of trains; and a clear waterway of 28 feet is also provided for the canal. The bridge, weighing twenty tons, is raised or lowered, in less than two minutes, by winches moving the chains, and turned by two men. The bridge moves between two brick arches, spanning the canal, and serving as footbridges, having a span of 79¾ feet, a radius of 43 feet, and a height at the crown of 21 feet above the water-level of the canal. The winches are worked on the top of these arches; and the girders carrying the pulleys and guiding rollers of the four lifting chains, rest on these

arches and on four brick piers at the ends of the arches, down the outer sides of which the counterpoise weights hang with compensating chains of equal weight below. Since the erection of this bridge, in 1868, it has needed only very slight repairs. The level of the rails is only 2½ feet above the highest water-level of the canal. Two bridges, similar in principle, have been built across the Oswego Canal at Syracuse, U.S., where the lift is effected by hydraulic power, which is an advantageous addition where the span is larger and the railway traffic greater.

L. V. H.

Propagation of the Tide in Canals and Rivers.

By — CLAVENAD.

(Le Génie Civil, vol. vii., 1885, p. 196, 12 woodcuts.)

The influx of the tide up rivers or canals is marked by the formation of a series of small waves following one another on the surface of the water, gradually raising the water-level, and often coalescing, so as to create more or less of a bore. These tidal-waves travel with a velocity represented by $\sqrt{g\,d}$, where d is the depth. In the progress of the tide up a channel, each section of water experiences a certain forward displacement; but the velocity of this motion is generally very much less than the rate of propagation of the tide. The tidal-wave ascends the small incline of bed found in wide estuaries without appreciable retardation, so that, for instance, in the case of the Seine, high-water level is higher at Tancarville than at Havre. If the water in the channel has no current, the tide will progress unimpeded as indicated above. If, however, there is a fresh-water flow, it will furnish its supply towards filling the estuary during the flood-tide; if this discharge is more than sufficient for the purpose, a current will continue to flow down towards the sea; if not, the flow will be up the estuary, and its velocity will be the difference between the velocity of penetration, due to the tidal action, and that of the river corresponding to the total section. During the ebb, the velocity of evacuation will be joined to that of the river current. Although the flood and ebb currents will approximate to what the Author terms the currents of penetration and evacuation, they will be somewhat more rapid in certain cases owing to the smaller amplitude of the displacements in the deep parts. In shoal places the discharge of penetration and evacuation will be impeded, and the flood and ebb currents will increase in speed; and when the supply of water becomes inadequate, the waves will be liable to break. If the shoal extends for some distance, a normal flow will be established, but with the result of a lower tidal range and an increased velocity of current. The velocity of penetration, U, at any point, where d is the depth at low water, after a rise

of tide during a time t, and assuming that the tidal curve may be represented by the equation $y = \phi(t)$, is given by the equation, $U = \frac{2\sqrt{g}}{3} \frac{\phi(t)^{\frac{3}{2}} - d^{\frac{3}{2}}}{\phi(t)}$. Where the velocity of the river corresponding to the whole section is V, the velocity of penetration is $U - V$. The above formula shows that the velocity of the flood-tide is greater in proportion as the natural depth of the river or canal is less, as may be readily noticed in rivers with a bar at their mouth, or on flat beaches. The velocity of evacuation is given by the formula, $U_1 = \frac{2\sqrt{g}}{3} \frac{d^{\frac{3}{2}} - \phi(t)^{\frac{3}{2}}}{\phi(t)}$.

The Author then proceeds to investigate, by means of equations and diagrams, the curves of the tide, and the bore, under various conditions; and he concludes by applying his method to the tidal Seine. Eliminating complicated local conditions, and assuming the Seine to have a level bed, and a depth of 7½ feet below the lowest tides, and neglecting the velocity of the river-current, owing to its small summer discharge as compared with the tidal volume of a spring tide, a diagram of tidal lines and of the bore is drawn out for a period of twelve hours. Under these conditions, the diagram indicates that the tide extends up the river to a distance of 105 miles, and that the bore is raised over 10 feet, and its velocity is about 23 feet per second. These figures correspond approximately to the actual facts; and doubtless the coincidences would be much more marked if a detailed investigation was attempted with the various necessary data.

L. V. H.

Navigation on the Rhine in 1882. By B. de Mas.

(Annales des Ponts et Chaussées, 6th series, vol. ix., 1885, p. 541, 1 plate.)

The Rhine after entering Germany may be divided into five sections, according to the countries which it separates or traverses. The last three sections, Hessian, Prussian, and Dutch, comprising the river below Mannheim, are alone of interest as regards navigation. The length of river within German territory, from Basle to Emmerich, is 423 miles. In Holland it possesses a double waterway between Emmerich and Rotterdam, 89 miles long by the Waal, the Morwede, and the North and New Maas, and 93 miles by the Lower Rhine, the Let, and the New Maas. The average fall of the river from Basle to Emmerich is 21½ inches per mile, whilst from Mannheim to Emmerich it is only 11½ inches per mile. The average velocity of the current, when the river is at a mean height, is 3 miles an hour. The falls and velocities, however, are very unequally distributed, attaining their maximum between Bingen and St. Goar, where the average fall is 29 inches per mile, and in

some places nearly double this amount. The navigability of the Rhine in 1882, as a whole, was far from perfect, for an unusual and continuous low-water level in the first half of the year, and large and frequent floods in the second half, caused frequent interruptions in the navigation. Steam-traffic was entirely stopped for about ten days in the year, and subjected to restrictions for sixty or seventy days; whilst the passenger-steamers and other craft were stopped for a much longer time. The total tonnage of vessels entering and clearing the Rhine ports in 1882 amounted to about 10,000,000 tons. Details are given in several tables of the traffic at the various ports, the weights of the different kinds of merchandise, and the costs of carriage to the principal ports in each month. The traffic is carried on by over four thousand vessels belonging to a great number of different companies and shipowners, which causes a brisk competition and low freights. The freights from Rotterdam to Cologne ranged between 0·3*d.* and 0·16*d.*, and from Rotterdam to Mannheim between 0·25*d.* and 0·16*d.* per ton per mile, according to the merchandise; whilst from Mannheim and Cologne to Rotterdam it ranged between 0·28*d.* and 0·16*d.* per ton per mile. Almost all the trade is conducted by vessels and barges towed by steam-tugs; only 7 per cent. of the merchandise is carried on steamers direct, and the traffic of vessels unaided by steam is insignificant. The tugs of the Rhine are large, very tapering vessels; some of them have engines of from 600 to 700 HP., and they are provided with all the latest improvements for economizing fuel. Vessels with two screws are preferred, as combining adequate power with small draught; nevertheless, when the river is very low, paddle-wheel tugs of the old type have to be resorted to. Towing by aid of a submerged cable was started ten years ago, but it has not afforded satisfactory results, and has been abandoned, except in the most difficult part of the river between St. Goar and Bingen, where it has proved serviceable, especially when the water is low. A serious disadvantage of the system is that in descending the river the tug has to let go the cable and act simply as a tug, for which it is not well suited. Improvements have been introduced in the vessels as well as the tugs; narrow iron vessels have been substituted for the broad wooden barges, to reduce the tractive force. Some of these vessels are 1,000 tons register; but vessels of from 400 to 500 tons are the most common. On the Rhine, vessels forming one convoy are not connected together in trains as in France, but each is provided with its tug, which is a great advantage where the navigation is difficult. The large traffic on the Rhine, in spite of its rapid currents, its variable state, and its comparatively small depth, and the commercial importance of the two adjacent inland ports of Mannheim and Ludwigshafen, suggest what a development the port of Lyons would be capable of with a suitable system of river transport. Trans-shipment would be necessary at Lyons, owing to the different class of craft required for canal- and river-navigation; but the merchandise arriving at Mannheim is trans-

ferred to the railways, whereas goods could be conveyed into the interior of France from Lyons by water-carriage, at very cheap rates.

L. V. H.

Improvement of Rocky Portion of Missouri River.

(Report of the Chief of Engineers, U.S. Army, 1883, part ii., p. 1344.)

The training of the lower sandy portion of the river which is still being carried on has been previously referred to.[1] A careful survey of the rocky portion of the river was made in 1882–83, with the object of regulating its channel. The river has an average depth of only about 3 feet, so that vessels of very light draught and of great width and length in proportion to their depth have to be employed for navigating it. The width of the river varies from about 400 to 1,000 feet; whilst its mean depth nowhere exceeds 8 feet, and in some places is under a foot in the portion recently surveyed. Obstructions to navigation are caused by shoals, due to an excessive widening out, or to the stream dividing into two or more branches, and also to boulders. Tables of rainfall in the river are given for several years, from which it appears that the greatest rainfall generally occurs in May; but the winter rains have a great effect on the average depth of water in the river; whilst after June the water is chiefly derived from melted snow. The mean velocities given by the formulas of Humphreys and Abbot, Darcy and Bazin, and Ganguillet and Kutter were compared with the observed velocities at different stations; and their mean errors were, H and A, 0·8606; D and B 1·0867; and G and K, 0·5431 foot per second. Accordingly, Kutter's formula was adopted for computing the discharge of the river at various stations and for different stages. The value of the coefficient of roughness, N, at nine different stations, was deduced from the formula of mean velocity; it varied between 0·0162 and 0·0644. The discharge of the river at its lowest known stage was found to be 3426·14 cubic feet per second. The object of the improvement-works is to secure a minimum depth of 2½ feet at the lowest known stage of the river. The works consist in removing rocks from shoal places, and forming wing-dams in wide places so as to produce a head of water on the shoals sufficient to secure the required depth. The contraction of channel, or length of dam, needed to obtain the proposed increase in depth, is approximately determined at the various places by taking the mean of the results given by the several formulas of Cresy, Eytelwein, Weisbach, Bresse, D'Aubuisson, and Debauve. An example is given of the method by which the length of wing-dam, necessary to obtain the requisite increase in depth of half a foot at Tables Rapids, is

[1] Minutes of Proceedings Inst. C.E., vol. lxv., p. 404.

determined. The mean value for the width of the contracted channel is found to be 318 feet, requiring a dam 307 feet long. From a table of the steam-boats navigating the Missouri above Bismarck, it appears that several of these vessels can carry from 75 to 100 tons with 2 feet draught, and over 200 tons with 3 feet; whilst one vessel of over 1,000 tons navigates the river.

L. V. H.

Clearing away Wrecks in the New Fairway to Rotterdam.

By F. Doffegnies.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1885, p. 133.)

The Author describes the clearing away of the wrecks of the steamer "Anastasia," of 650 tons, eight years old, with a cargo of grain, which sunk in the fairway between the jetties at the Hoek van Holland on the 11th of May, 1883, and of an iron hopper-barge of 53 tons, sunk in September, 1878, near the same place.

In June 1883 a contract was entered into between the Public Works Department and Messrs. Newton Brothers of Hull, by which these gentlemen agreed to remove the wrecks above mentioned from the fairway by means of their patent wreck-torpedoes, so that no obstructions should remain to within 7·50 metres below mean low-water level. To assist in keeping silt and sand away from the wrecks, Messrs. Volker and Bos were contracted with to remove 75,000 metres of sand from the spot over a surface five times that taken up by each of the wrecks. Messrs. Volker and Bos began operations on the 13th of May, 1883, by excavating the sites with four of their suction-dredgers, and removing, up till the 11th of July, altogether about 33,000 metre cubes of sand. On the 14th of July Messrs. Newton Brothers torpedo cutter "Albatross," Captain Rose, arrived on the spot, and after a preliminary survey by a diver at once proceeded to place and explode some torpedoes. On the 30th of July, notwithstanding several days of bad weather, twenty-five torpedoes, with a total charge of 700 lbs. of tonite, had been used on the wreck of the barge.

As circumstances permitted the work on both wrecks was continued through the summer of 1883, alternately clearing the sand from the spot or exploding torpedoes whenever pieces of iron were found to protrude from the bottom. On the 8th of December the work was ceased for the winter.

On the 26th of April, 1884, the suction-dredgers were again sent to work on the spot, and on the 21st of May several heavy pieces of iron were fished up and carried out of the fairway. The work continued on the same system as the year before, alternate dredging and exploding all through the summer till September; On the 19th of that month an official inspection was made, and no parts of the wrecks were found at a less depth than the stipulated

7·50 metres at low water. The total cost was 115,047 florins, of which 86,247 florins was for dredging 114,996 cubic metres of sand and silt, and the amount of 28,000 florins for Messrs. Newton Brothers' contract. Besides these, four other wrecks were removed at a cost of 3,728 florins during the same time. These, however, were not in the fairway, and were only cleared away to 4 metres below low water. The Paper is accompanied by two drawings, showing the situation and the progress of the work.

H. S.

Construction of Quay-Walls for a Ninth Dock at Havre.

By E. Widmer.

(Annales des Ponts et Chaussées, January 1885, 2 pl.)

The west basin of the Ninth Dock at Havre has been designed to have a length of 1,440 feet, and a width of 720 feet. About two-thirds of its walls, amounting to 2,790 lineal feet, had to be built in the Eure creek, on a foreshore covered with water at every high tide to a depth of from 6½ to 13 feet; and the foundations had to be carried about 26 feet below the surface of the ground. These walls have been built on a series of eighty-four wells, formed by rubble masonry blocks, 33 feet long, 22 feet wide, 26 feet high, and having a central hollow of 18⅓ feet by 7½ feet, enlarged at the base to 21⅔ feet by 10⅝ feet. Alternate wells were first sunk, and the intermediate ones were only undertaken after the first had reached their foundations, so that the sinking of a well might not disturb its neighbour. An interval of 3¼ feet was left between the blocks. The rubble masonry blocks were made with Portland cement mortar; they were first built to a height of 14¾ feet, and left to set for thirty days; the silt was then removed from the interior of the well, so that the block sunk to its full depth. The masonry was then built up to the full height, and left twenty days to harden; and the sinkage was then recommenced till the block reached its foundation, in a stratum of clay 3¼ feet below dock-bottom; and, lastly, the well was filled up with concrete. The first block was commenced in April 1881, and the last one was completed in March 1884; they contain altogether 58,800 cubic yards of masonry and concrete. The first course of masonry was simply laid on ordinary planks placed on the top of the clay underlying a surface layer, about 3 feet thick, of sand or silt. One block only failed in the process of sinking, one of the walls of the well being forced inwards at the bottom owing to its not having been left the full time for setting. This failure was repaired by underpinning, on a platform hung by bolts from the sound portion of the block. The wells were kept clear of water at first by hand-pumps, and subsequently by steam-pumps. The excavation was performed by four men in the well; and the material was lifted in wooden skips, containing about 2 cubic feet, and deposited by barges

at high water at a distance of not less than 100 feet off. During the latter half of the work, the actual construction and sinking of the blocks occupied one hundred and twelve tides of from five to five and a half hours in duration, employed as follows: Construction of lower 14¾ feet, twenty tides; first sinkage, twenty-six tides; completion of block, sixteen tides; second sinkage, forty-four tides; filling well with concrete, six tides. The influx of silt, which frequently occurred during the sinking, was checked by straw, fascines, or sacks of earth. The volume of material thus introduced amounted to about 45 per cent. of the actual space occupied by the block. The contract price for sinking the blocks was 12*s.* 1½*d.* per cubic yard of block sunk below the surface of the ground. An ample estimate of the actual cost of the work, per cubic yard of block sunk, gives the following result: Cost of excavation, 5*s.* 6½*d.* + proportionate cost of plant, 2*s.* 6½*d.* = 8*s.* 1*d.* total cost per cubic yard of block. The sinking of these open wells, exposed to the sea and tide, has succeeded perfectly, owing to the dimensions adopted for the blocks, the use of Portland cement, and the time allowed for the setting of the mortar. The system, moreover, has proved cheaper than the method of compressed air would have been, and might therefore be advantageously resorted to for other works similarly circumstanced.

L. V. H.

Port of Dieppe. By Henry Couriot.

(Le Génie Civil, vol. iv., 1884, pp. 72 and 88, and vol. v., p. 377, 1 pl. 5 woodcuts.)

Dieppe occupies the seventh place amongst French ports, in respect of the tonnage of its merchandise, owing to its having attracted the greater part of the trade between England and France in consequence of its being in the direct line between Paris and London, and the nearest seaport to Paris, as Newhaven is to London. The weights of its imports and exports have been trebled in twenty-five years; for they were 201,300 tons in 1857, and 679,600 tons in 1882; whilst the rise in the value of its merchandise has been still more rapid, having increased from £1,200,000 in 1857 to £6,960,000 in 1881. Nevertheless its trade since 1878 has remained nearly stationary; whereas the progress of the neighbouring ports of Havre, Rouen, and Dunkirk has been maintained. This check in its trade must be attributed to the defective state of its old port, for its quays were amply equipped. Accordingly, the improvement and enlargement of the port were decided upon in 1880; and the jetty-works will be completed in the course of the present year (1885). The anchorage is good in front of Dieppe, but there is no shelter for vessels waiting to enter the port. The only dangerous part is the bar of shingle in front of the jetties, which varies in height and position, but was only about 3 feet above low water of spring tides in 1883, at its highest

point, and left a wide channel at about low-water level. The old port consisted of a curved irregular entrance channel guided by jetties, having a depth maintained at the level of low-water spring-tides; a tidal harbour, 1,300 feet long, at right angles to the entrance channel and having an area of 16 acres, which was exposed to the entering swell; a gridiron, 165 feet long, along the south quay, which formed the sole accommodation for the repair of vessels; the two docks Duquesne and Berigny, having areas of $9\frac{1}{8}$ and $8\frac{7}{8}$ acres respectively, and entered from the tidal harbour through the Duquesne entrance, which is out of the central line of the channel, and has its sill $5\frac{1}{3}$ feet above low-water spring-tides, so that the depth of water over it at high-water neap-tides is only $17\frac{3}{4}$ feet; and, lastly, a sluicing-basin whose site has been appropriated for the dock-extensions. The new works comprise the improvement of the entrance-channel; the formation of a new channel, in a line with the entrance-channel and leading into a new tidal harbour; and the construction of a half-tide basin and a dock, opening out of the new tidal harbour, on the site of the old sluicing-basin. The estimated cost of the works is £640,000. The entrance-channel has been regulated by removing the east jetty and reconstructing it parallel to the west jetty, so as to give the channel a minimum width of 230 feet, instead of 148 feet, and a width of 246 feet at the entrance. The west jetty is to be eventually lengthened 328 feet, to arrest the shingle which reached out to the old pier-head. Only the first half of this extension has been as yet undertaken, for it is preferred to defer the second extension till the effects of the first have been ascertained. A depth of $8\frac{1}{4}$ feet below low-water spring-tides is to be gained by dredging from that depth in the sea, in front of the entrance, right up the channel and into the old tidal-harbour. The east jetty has been made open for a length of 500 feet from the pier-head, with light frames of wrought-iron carrying a roadway on the top, so as to admit the entering swell into a stilling-basin formed at the end of the jetty, 227 feet wide. The object of the new channel, cut across a portion of a suburb, is to obviate the inconvenient bend formed by the old tidal-harbour, and to afford direct access to the new docks. It will open into a new tidal-harbour of nearly 10 acres. The old entrance, which afforded communication between the Duquesne dock and the sluicing-basin, now opens into the new tidal-harbour, and will provide a second entrance for the old docks. The depth of the new tidal-harbour is 5 feet below low-water. A graving-dock, opening into the harbour, will furnish means for the repair of vessels. The half-tide-basin, 490 feet long and 330 feet wide, will serve as a large lock, having an entrance, 59 feet wide, at each end, one opening into the tidal-harbour and the other into the new dock. The lower entrance, $98\frac{1}{2}$ feet long at the coping, was founded on the chalk, at a depth of 22 feet below low-water, by means of a plate-iron caisson sunk by compressed air. This caisson, 116 feet by 110 feet, and over 56 feet high, had to be weighted with a load of 12,000 tons of shingle

placed on the roof of the working-chamber. The upper entrance was founded on gravel, at a depth of 12 feet below low-water, under shelter of a cofferdam. The new dock, 360 feet wide, is being given a temporary length of 984 feet, with pitched slopes on the south and east sides, so that it may be eventually extended to meet the growing requirements of the port. The quays are to be provided with hydraulic machinery for working the bridges, gates, sluice-gates, and capstans. The commencement of the new cut has been hindered by the delay in getting possession of the houses on its site; but it is to be completed in 1886, by which time the dredging in the entrance channel and outside is to be finished. The dredging-plant is to be capable of removing about 2,000 cubic yards of material per day of twelve hours, or half that quantity of chalk, and two-thirds of these amounts when there is a moderate swell. The barges are to deposit their loads between Dieppe and Puys, at least half a mile away from the jetties.

L. V. H.

Charleston Harbour Improvement.

(Report of the Chief of Engineers, U.S. Army, 1883, part i., p. 873, 2 plates.)

A design was completed early in 1878 for forming and maintaining a low-water channel, 21 feet deep, across Charleston bar, by means of two low converging jetties, at an estimated cost of £375,000, where formerly the available depth did not exceed 11½ feet. The north jetty was commenced in December 1878, and had been carried out 14,361 feet from its starting-point on Sullivan's Island by the middle of 1882. A bottom course of mattresses, formed of logs and brush, was laid along the whole length, varying in width from 43 feet at the shore to 118 feet at the outer end, and in height from 2½ to 4 feet. From 7,000 feet from the shore, the jetty was raised to a height of about 6 feet by a second course of mattresses for a length of 1,648 feet; and the outer portion, beyond an intervening shore, was raised by rubble stone to a maximum height of 14 feet. Altogether, 93,900 cubic yards of stone, and 144,000 square yards of mattresses, averaging 18 inches in thickness, had been placed in the north jetty by the middle of 1882; and no further work was done to this jetty during the year 1882-83. The south jetty was commenced in April, 1880, and had been carried out 12,780 feet from Morris Island by the middle of 1883; 73,900 cubic yards of stone, and 178,200 square yards of mattresses having been deposited in the work. Towards the close of 1881, strong currents were observed setting across the foundations of the outer end of the south jetty; so the bottom course was increased at intervals of about 70 feet, by laying mattresses 130 feet wide, in place of the ordinary width of 108 feet, forming short spurs to protect the jetty from undermining by scour. About the same period, a change was introduced in the mode of laying the founda-

tion mattresses, by which they were made to overlap from 10 to 20 feet, thus avoiding gaps between them and preventing loss of stone besides slightly increasing their height. The construction of spurs was extended, towards the end of 1882, by laying projecting mattresses, 100 feet long and 50 feet wide, on each side, about 200 feet apart, and only lapping a few feet on the foundation course so as to secure the jetty more effectually from being undermined. These jetties, after converging to a width between them of 2,900 feet, are to be run out parallel up to their terminations. The depth of water has been already improved, and the area of the shoals reduced; but the jetties must be carried further out and raised higher before decisive effects can be produced. A rapid completion of the work is urged to secure the benefits anticipated. The total cost of the works, up to June 30th, 1883, amounted to £197,000; but it is extremely doubtful whether the work can now be completed within the original estimate, owing to the small and intermittent appropriations that have been hitherto made.

L. V. H.

Chicago Harbour Improvement.[1]

(Report of the Chief of Engineers, U.S. Army, 1882, part iii., p. 2203, 1 plate; 1883, part ii., p. 1741, 1 plate.)

The enclosed harbour at the mouth of the Chicago river, completed in 1880, has been previously described. The design of an exterior detached breakwater, for forming an outer harbour, was also referred to; and this breakwater is now in course of construction. The first crib, 36 feet long, was sunk in July 1881, in the centre point of the breakwater, whose total length is to be 5,436 feet. Twelve more cribs, each 100 feet long, were laid that year before the close of the working season, and three more before the middle of 1882, completing a total length of 1,443 feet of breakwater in 1881–82. The cost of the work was found to amount to about £22 18*s.* per lineal foot. Owing to the suspension of the works for six months, only eight more cribs were sunk in 1882, and one more before the middle of 1883. A superstructure was also placed on the breakwater, 4 feet high. The breakwater was struck several times by vessels entering and leaving, and somewhat damaged. The length of breakwater actually completed by the middle of 1883, was 1,936 feet, leaving 2,300 feet on the south-east side, and 1,100 feet on the other still remaining to be constructed.

L. V. H.

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[1] Minutes of Proceedings Inst. C.E., vol. lxiv., p. 382; and vol. lxxi., p. 464.

Galveston Harbour-Entrance Improvement.[1]

(Report of the Chief of Engineers, U.S. Army, 1881, part ii., p. 1326, 2 plates; 1882, part ii., p. 1441, 3 pl. 2 woodcuts; 1883, part ii., p. 1059, 2 pl. and 1884, p. 1295, 1 pl.)

The design approved in 1880 consisted in carrying out two slightly converging jetties across Galveston outer bar, for increasing the depth of the channel over it from 12 feet to 20 feet. The inner bar had previously been lowered from 11 feet to 20 feet by training works. A trial section of mattress work, 90 feet long, 60 feet wide, and 2½ feet high, ballasted with concrete, was deposited for the north jetty in 1880; but no further work has been done at this jetty. The south jetty was commenced in July 1880 by depositing mattresses weighted with stone, whose construction and section are shown on the plates of the 1881 report; and 7287 lineal feet of foundation mattresses were laid during the year 1880–81, from 60 to 90 feet wide. During the year 1881–82, the length of foundation mattresses was increased to 20,777 feet, from 30 to 120 feet wide, of which 10,130 feet were raised by a second layer. The materials for the mattresses had to be brought a distance of from 30 to 75 miles, and the stone conveyed 140 miles by rail. By the middle of 1883, the foundation course of the south jetty had reached a length of 22,551 feet, from 60 to 120 feet wide, with a second course from 15 to 30 feet wide upon it; and third and fourth courses had been placed on the top, 12,500 and 4,000 feet in length respectively. In 1881–82, 84,086 cubic yards of brush mattresses, and 27,307 cubic yards of ballast, were deposited in the south jetty, at a cost of £66,956, or about 12*s*. per cubic yard of jetty. The following year, 71,657 cubic yards of mattresses, and 35,897 cubic yards of stone, were deposited in the south jetty, at a cost of 11*s*. 9½*d*. The channel over the inner bar reached a minimum depth of 25 feet in 1883. The changes in the jetty channel have been small, considering the magnitude of the jetty works. The channel has been deepened 1½ foot at the shallowest point, and has been straightened. The bar had shifted out into the gulf about 300 feet, and it has somewhat narrowed; but the depth over its crest has not been increased. During the year 1883-84, 27,906 cubic yards of mattresses and 10,297 cubic yards of stone were deposited in the south jetty at a cost of 13*s*. 2½*d*. per cubic yard of jetty, raising the jetty and filling up the gaps. The channel over the inner bar gained one foot during the year, reaching a depth of 26 feet. The depth, however, of the jetty channel over the outer bar remained unchanged at 13 feet at mean low tide; whilst the bar has advanced 350 feet on the average into the gulf in the year. This state of things confirms the opinion, expressed a year ago,

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[1] Minutes of Proceedings Inst. C.E., vol. l., p. 206.

that in order to gain an increase in depth over the outer bar, and to preserve it when obtained, the construction of the north jetty, as soon as possible, is absolutely necessary.

L. V. H.

Harbour of Refuge, Milwaukee Bay, Wisconsin.

(Report of the Chief of Engineers, U.S. Army, 1881, part iii., p. 2113, 1 woodcut; 1882, part iii., p. 2155; 1883, part ii., p. 1703, 1 plate.)

Milwaukee Bay is situated on the west coast of Lake Michigan; it is 8 miles wide between the enclosing headlands, and 2 miles deep. It serves as an outer roadstead for Milwaukee Harbour, situated in the bay at the mouth of Milwaukee River, and furnishes good anchorage-ground and protection, except from north-east to south-east. A plan for converting a portion of the bay into a refuge-harbour was approved in 1881, and is now being carried out. It consists in the construction of a sheltering cribwork breakwater. The breakwater starts at a distance of 600 feet from the shore, south of North Point, and proceeds in a south-easterly direction for a length of 2,400 feet, whence, making a slight bend westwards, it is to extend for a distance of 5,200 feet, in a south-south-westerly direction, toward the entrance of Milwaukee Harbour, leaving a gap of 400 feet at 1,000 feet south of the bend to serve as an entrance. Further protection will be afforded for the south-east, if found necessary, by a detached breakwater, lying between the southern extremity of the main breakwater, and the entrance piers of Milwaukee Harbour, leaving an entrance of 1,000 feet between the extremities of the two breakwaters. The sheltered area, having a depth of over 18 feet, will exceed 460 acres. The breakwater was commenced at its northern extremity by sinking the first crib in August 1881, in 8 feet of water. During the year 1881–82, twenty-two cribs were sunk and filled with stone, carrying the substructure of the northern arm of the breakwater out to a length of 1,400 feet, and into a depth of 22 feet. The first six cribs are each 100 feet long and 20 feet wide, rising 2 feet out of water; and the rest of the cribs have been made 50 feet long, 24 feet wide, and rising 1 foot above the water-level. The northern arm, with the exception of the superstructure, was completed in August 1883, having a total length of 2,450 feet. Beyond the first 1,600 feet, the cribs have been sunk upon a rubble base, levelled off at a depth of 20 feet below the water-level, and extending 10 feet beyond the cribs on the lake side, and 6 feet on the land side. The outer 150 feet of this arm are to be raised 6 feet above the water, and the remainder 2 feet. The estimated cost of the whole work is about £167,000, of which £10,836 was expended in 1882–83.

L. V. H.

Iron Longitudinal Sleepered Permanent Way for Main Lines.

By — BURKHARDT.

(Organ für die Fortschritte des Eisenbahnwesens, 1885, part iv., p. 121.)

The rails for which this system of iron sleepers is designed are of the ordinary flat-bottomed pattern, 5 inches deep, 2·3 inches wide at the top flange, 3·35 inches at the bottom, and 20 feet 6 inches long. The longitudinal sleeper on which the rail rests directly is an inverted channel iron with sloping sides, width on the top 9·76 inches, depth 2·36 inches, width over flanges 12·6 inches, and length 27 feet 10½ inches. One of the open ends of the sleeper is closed by a plate riveted to the limbs of the channel-iron, and the other by one of the cross-ties, which connect the two sleepers. One of the peculiarities of the system is that the longitudinal sleepers are not directly connected at all with the sleepers before and behind them, there being a clear space of 1 foot 7½ inches between the ends of consecutive sleepers, this space being directly under the joint of the rail. The rail joint is made with deep fish-plates of a new pattern, which are so formed that when the joint is screwed up the pressure is entirely on the flanges of the rail, the web being untouched by the fish-plates. The moment of resistance of the two plates is as great as that of the rail and sleeper together. As the fish-plates project about 2 inches below the top of the sleeper and there is only just clearance, any creeping of the rails on the sleepers is impossible. The rail is attached to the sleeper at nine points, 3 feet 5¼ inches apart centres, by means of a screw-bolt, binding plate and bent washer on each side of the rail. The rail is bent to the required curve before fixing. The binding plate (3¾ inches × 1½ inch × ¾ inch thick) rests upon the sleeper and overlaps the bottom flange of the rail about ⅝ inch. It has a rectangular hole through it to admit of the passage of the holding down screwbolt and allowing of sufficient play (at right angles to the rail) to admit of the adjustment of the rail to the required curve, the bolt-hole in the sleeper being in constant position. The upper surface of the binding plate is serrated, and a washer, with corresponding serrations, lies upon it; through this the bolt passes. The slot in the binding plate admits of the washer moving about ¾ inch each way, which is enough for the adjustment of the sharpest curve. The washer has a vertical limb which fits into a hole in the sleeper. The bolt, which passes through washer, binding plate, sleeper, and cross-tie, is so arranged that it can be put in from the top.

The cross-ties, of which there are three to each pair of sleepers, consist of a peculiarly-shaped angle or channel-iron 6 feet 7 inches long and 4 inches deep. At each end this is attached by three rivets to the vertical limb of an ordinary angle-iron, whose horizontal limb has two holes corresponding with the holes in the sleeper, and through which pass the bolts which hold down the

binding plate and washer described above. This angle-iron is riveted at an angle of 1 in 20 with the cross-tie, and thus gives the necessary inward inclination of the rail.

For curves of 25 to 45 chains radius the cross-ties are made ¼ inch longer, and for curves of 14 to 22 chains ½ inch longer than the normal length.

The order of fixing the rail is as follows: laying the straight or previously bent rail upon the sleeper; putting in the bolt from above; turning the bolt round 90°; fixing the binding plate and washer and putting on the nut; pushing the binding plate into its exact place and screwing up.

The ballast is levelled up to the top of the binding plate, and the form of the cross-tie and the clear space between the sleeper ends conduce to its good drainage.

The advantages claimed for the system are as follow:—

1. There is only one pattern of sleeper, straight and uniformly holed.
2. There is no jointing of the sleepers.
3. The continuity is complete. The rail joint is suspended.
4. The drainage of the ballast is assisted by the form of the cross-ties.
5. The gauge and the curving of the rails are unchangeably preserved.
6. The laying of the way is simply and quickly carried out.
7. In proportion to its carrying power the weight of the permanent way is less than that of any known system.
8. All the fastenings are visible, and the bolts are put in from above, which makes the inspection and maintenance easy.
9. The number of different pieces to be kept in stock for maintenance is a minimum.

The weights are as follow:—

——	No. of Pieces.	Weight.	
		Each.	Total.
2 rails, 29 feet 6 inches long .	2	58 lbs. per yard	1142·8 lbs.
2 sleepers, 27 feet 10½ inches long	2	59·7 lbs. „	1108·8 „
2 sleeper ends	—	2 6 lbs.	5·3 „
4 fish-plates	4	23·3 „	95·2 „
8 fish-bolts	8	1·8 „	14·1 „
3 cross ties	3	65·6 „	196·8 „
36 rail fastenings	108	2·1 „	74·6 „
	127		2637·7 „

Weight per lineal yard . . . . . . 268 lbs.
No. of pieces per lineal yard . . . . 12·9.

TABLE FOR COMPARISON WITH OTHER SYSTEMS.

—			Name of System.				
			Hilf.	Rhanbahn.	Haar-mann.	Hohe-negger.	Burk-hardt.
Rail.	Length	feet	29½	29½	29½	29½	29½
	Depth	ins.	4·72	5·12	4·92	4·92	5·12
	Weight per yard	lbs.	64·8	63·9	64·8	64·5	63·5
	Moment of inertia	cm.	670	823	766	773	864
	Moment of resistance	„	105	115	114	120·4	126
Sleeper.	Length	feet	29·27	29·20	29·50	29·45	27·86
	Depth	ins.	2·36	2·36	2·95	2·95	2·36
	Breadth at bottom	„	11·81	11·81	12·59	11·81	12·59
	Weight per yard	lbs.	59·27	46·37	51·21	58·97	59·67
	Moment of inertia	cm.	113	160	149	154	125
	Moment of resistance	„	22	26	35·6	27·5	29
	Moment of resistance of rail and sleeper together	cm.	127	141	149·6	147·9	155
	Distance apart of rail fastenings	feet	2·48	3·00	3·02	2·50	3·44
	Total weight per lineal yard	lbs.	260	231·8	272·2	284·2	268
	Number of pieces per yard		..	..	10·6	14·1	12·9

The Paper is illustrated by detailed drawings.

W. B. W.

Notes on the Permanent Way of Light Railways.

By J. W. POST, Engineer to the Netherlands State Railways Company.

(Revue Générale des Chemins de fer, vol. vi., p. 259.)

The first concession for light railways on the 1·5 metre gauge, given under the law of 9th August, 1878, by the Dutch Government, was to the Geldersche-Overysselsche Company, for lines of a total length of 135 kilometres. The Author describes the system of permanent way adopted for this railway, constructed under his superintendence. At present steel rails and red pine sleepers, 1 metre apart, are used, but it is intended to replace the wooden by metallic sleepers. The rails are of the Vignoles type: height, 120 millimetres; width of bottom flange, 90 millimetres; sectional area, 32·6 square centimetres; and weight, 25·6 kilograms per metre length. The standard length of rail is 9 metres. The price paid for rails between 1882 and 1887 was 70·62 florins per ton of 1,000 kilograms, or £5 8*s*. 6*d*. The fish-plates are steel, the outside plate with an angle bent outwards, to stiffen the joint, rests on two sleepers. To prevent the rails from creeping, a dog-spike is driven at each end against this flange.

The same price per ton was paid for the fishplates as for the rails. Grover spring-washers, of cast steel, are used with all bolts. These only cost 11 florins per thousand. The total weight of metal per lineal metre of permanent way is 55·6 kilograms. At the points the rails are placed vertical; the outer rails are not lifted in the curves. The maximum widening of gauge in the curves is of 20 millimetres. The angle of crossing is 1 in 9 in all cases, and the total length of a set of points and crossings is 24·01 metres. The points can therefore be laid on the existing track without cutting up the rails. The switches are shaped to a curve of 180 metres radius, and only 7·50 metres long, and carefully planed to exact shape. No part is longer than 6 metres, to facilitate carriage. The crossings are of a total length of 2·16 metres, and joined to the rails at each end by straight fishplates. The packing-pieces between abutting rails are specially cast for each end. The grooves are 44 millimetres wide, and 42·5 millimetres deep. The check-rails are 3 metres long. The points and crossings are laid on oak sleepers of 14 by 25 centimetres, and 55 centimetres apart. The cost per kilometre of permanent way, without ballast or laying, is 6,000 florins, and that for a complete set of points and crossings is 575 florins. The Paper is accompanied by several addenda and drawings.

H. S.

Advantages of Narrow-Gauge Railways. By AUGUSTE MOREAU.

(Memoirs de la Société des Ingénieurs civils, 1884, p. 557.)

The Author has for some years devoted much attention to the subject of narrow-gauge railways, and their suitability for accommodating the traffic-requirements of more or less thinly-populated districts, by putting them in railway communication with the main lines. Although these railways are especially adapted to districts where the traffic is limited, they are also capable of carrying an amount, in some instances very considerable, as on the Festiniog (North Wales) railway, where, with a gauge of only 2 feet, the traffic receipts are £2,253 per mile per annum. This compares favourably with the State Railway of France, a line of normal gauge (4 feet 8½ inches), earning £644 per mile. As regards speed, that obtained upon the Festiniog railway is 31 miles per hour, and, according to Mr. Fairlie, could with safety be increased to 45 miles per hour.

In France, since 1881, concessions have been granted for more than 1,864 miles of railways in outlying districts (Chemins de fer d'intérêt local), and, in the Author's opinion, there remain ten times that amount yet to be constructed, of lines necessary for bringing the villages of various districts into communication with the neighbouring towns and the main railway systems. These railways, however to be remunerative, must be constructed to a

gauge much less in width than that of the normal 4 feet 8½ inches, as a return of from £193 to £257 per mile per annum is at the present time regarded as a fair amount of traffic for a local line.

The cost of some of the narrow-gauge lines in other countries is given. In Norway, with a gauge of 3 feet 6 inches, the cost has varied from £3,154 to £5,342 per mile, according to the character of the country. In Sweden, where all the lines are narrow-gauge, varying from 2 feet 7 inches to 4 feet, the cost has averaged £3,862 per mile. In Brazil four-fifths of the railways are on a reduced gauge, varying from 2 feet 6 inches to 4 feet 6 inches in width, the greater part of these being to the 3 feet 3 inches (1 metre) gauge, and extending over a length of 2,983 miles. The remaining fifth (Dom Pedro II.) is to a gauge of 5 feet 3 inches (1·60 metre). The average traffic receipts of the narrow-gauge railways are £1,287 per mile per annum.

In Canada there is a length of 870 miles of railway laid to a gauge of 3 feet 6 inches. The cost of the Toronto, Grey, and Bruce, forming part of this system, was, without rolling-stock, £1,287 per mile. In Queensland some of the railways are of 3 feet 6 inches gauge, the speed being from 15½ to 18½ miles per hour, and the cost of construction from £5,986 to £9,977 per mile. The Ergastirian railway (Greece), with a gauge of 3 feet 3 inches, cost, complete, £4,814 per mile, in a country so rough as to necessitate tunnelling. Details are given of the permanent way and rolling-stock used on the narrow-gauge (2 feet 7 inches) railway between Rupertshof and Hennef, near Cologne, but the cost is not mentioned. In the French colonies the 3 feet 3 inches gauge is generally adopted, and the secondary lines of Algeria, of which there are about 3,760 miles yet to construct, will be to that gauge. A Table is given, showing the widths of the principal narrow-gauge lines in work or under construction in France and elsewhere, from which it may be seen that the reduced gauge most prevalent in France is 3 feet 3 inches; in Germany, 2 feet 6 inches; and in England, or those countries subject to English influence, 3 feet or 3 feet 6 inches.

The Author recommends that the width of gauge best suited for adoption in constructing local lines will, with few exceptions, viz., in very thinly populated districts, where the gauge might be made 2 feet 6 inches, be found to be 3 feet 3 inches and describes at length the economical advantages of this gauge as compared with that of the normal, viz., 4 feet 8½ inches. In earthwork the great saving is due partly to the reduction of the formation width, but in hilly districts far more to the avoidance of heavy embankments and cuttings, through being enabled more closely to follow the natural surface of the ground, by the adoption of curves of very much sharper radius, and gradients of greater inclination. The Author also demonstrates that with a gauge of 3 feet 3 inches the rolling-stock can with equal ease travel over a curve of less than half the radius of the equivalent curve on the normal gauge, and that the proportion of dead load to useful load

in the rolling-stock, being diminished in the case of the reduced gauge, therefore the inclination of the gradients may be made steeper.

The above considerations directly influence the area of land required, and a further saving under this head is effected by the avoidance of severance, and a reduction in the length of road and steam, diversions, &c. Bridges and culverts are similarly reduced in cube, and in many instances their necessity avoided, and the saving extends to workshops, carriage-, and engine-sheds. As regards the permanent way, the weight of the locomotives being only from 4 to 6 tons per axle, a rail weighing from 50 to 60 lbs. per yard suffices, and the sleepers are reduced from 8 feet 3 inches to a length of 5 feet 3 inches or 5 feet 11 inches, and are proportionately less in cross-section.

In the rolling-stock, the advantage procured by the adoption of the 3 feet 3 inches gauge, in diminishing the proportion of the dead to the useful load, is demonstrated as follows. Supposing all the dimensions of the two rolling stocks to be in the same proportion as the gauges, then the weight of the respective wagons will be as the cube of the gauges $\frac{p}{P} = \frac{3' \cdot 3''^3}{4 \cdot 8\frac{1}{2}^3} \overset{\text{Metre.}}{\left(\frac{1 \cdot 000^3}{1 \cdot 445^3}\right)} = \frac{1}{3}$ about, and the molecular resistance to flexure will be as the squares of the corresponding dimensions, $\frac{r}{R} = \frac{3' \cdot 3''^2}{4 \cdot 8\frac{1}{2}^2} \left(\frac{1 \cdot 000^2}{1 \cdot 445^2}\right) = \frac{1}{2}$ about. Therefore the wagon of the 3 feet 3 inches gauge will only weigh one-third of that of the 4 feet $8\frac{1}{2}$ inches gauge, but will be capable of carrying one-half the load of the latter. Dividing these into one another, $\frac{1}{3} \div \frac{1}{2} = \frac{2}{3}$, therefore the proportion of the dead to the useful load for a gauge of 3 feet 3 inches is two-thirds (0·666) only of what it would be for the normal gauge. In practice the diminution in the dimensions as above described, cannot be strictly carried out, but the proportion of the dead to the useful load may, in the 1-metre gauge, be assumed as 0·7 of that for the normal gauge.

The Author states that in England goods wagons capable of carrying 8 tons average a useful load of only 1 ton, and that as regards passenger traffic the number of persons actually carried is twenty-five for every one hundred seats provided. In France, as regards the goods traffic, the discrepancy is less marked, the average being 4 tons of dead weight to 1 ton of useful load; but the proportion for passengers is about the same as in England. In addition to the saving in dead weight, the wagons of the 3 feet 3 inches gauge are also better adapted for a local traffic where the separate consignments are likely to be small in amount. The passenger carriages of the 3 feet 3 inches gauge may with safety be made 9 feet 2 inches wide, thus affording five seats in each transverse row. A single central buffer is strongly recommended for narrow-gauge vehicles, as better adapted for sharp curves. It has been suggested that the normal gauge might be preserved, and at the same time the cost of construction in rough countries be

reduced to a minimum, by adopting sharp curves, worked with rolling-stock of the American bogie truck type, but one great objection to this is the increase in the dead weight of the vehicles, the proportion being 8 to 1 (with a full carriage), as compared with 3 to 1 on the 3 feet 3 inches gauge. The objections raised to the break of gauge, on account of the necessary trans-shipment, may be classified under the heads of working expenses, delay, and damage to goods. The first may be diminished to a cost of ½*d.* per ton, if proper arrangements are instituted. The question of delay is of little importance, as, where there is no break of gauge, a day is usually lost when a truck has to pass from one system to another. With regard to damage, the higher classes of goods being as a rule in small consignments, they form only portion of a truck load, and therefore would, with an unbroken gauge, have to be trans-shipped at the junction; whereas, in the instance of coals and other minerals, coal, &c., their trans-shipment would, under this head, be of little import.

Under present conditions, at the junction of two systems similar in gauge, a trans-shipment always takes place of incomplete loads, and, in addition, three-fourths the amount of all merchandise arriving in full wagons.

The saving in cost of construction of a line through an easy country is at least equal to the proportionate diminution of the gauge, viz., 33 per cent., increased in a rough country to 50 per cent. or 75 per cent.

The following are the costs of a few narrow-gauge lines, compared with what they would have amounted to if constructed with the normal gauge:—

			Normal Gauge.
1 metre gauge	Anzin to Calais	cost £4,956 per mile	(77,000 fr. per kilometre),
		was estimated at £12,872	(200,060 fr. „).
1 „	Hermes to Beaumont	cost £4,956 per mile	(77,000 fr. „),
		was estimated at £14,802	(230,000 fr. „).

Had the Corsican railways been constructed to the normal gauge, it was estimated that they would have cost from three to four times the amount actually expended on the 3 feet 3 inches gauge.

In the Rio Grande (Denver) railway the narrow gauge cost three-fifths of what the normal would have, and the Livonia (Russia) railway, with a gauge of 3 feet 6 inches (1·067 metre) realised an economy of 40 per cent. on the estimate for the normal gauge.

In conclusion, in adopting narrow-gauge lines, the public should have every facility offered it for using them, including simplification of classes, stopping-places at the crossings of all important roads, and commissions should be given to the hotel- and shop-keepers of the district for the sale of tickets. In France all the railways requiring the normal gauge have already been constructed, but there still remains an enormous length of narrow-gauge lines to be made, which, if carried out in an economical manner, would

reduce the cost from £9,655 (150,000 francs) to £12,172 per mile (200,000 francs per kilometre) for the normal gauge, down to £3,218 or £5,150 per mile (50,000 per mile, or 80,000 per kilometre) for the 3 feet 3 inch gauge.

D. G.

The Sorting of Goods Trains by Gravitation at Milan.

By Cecilio Arpesani.

(La Natura, 28 Dec. 1884, p. 408.)

The new goods station at Milan, situated on the line between the central station and that of Porta Genova, is the first that has been systematically laid out for sorting trains by gravitation.

The advantages of this system, as compared with that of shunting in the ordinary way, by locomotives, are chiefly that less space is required, greater rapidity, less wear and tear to rolling stock, and lastly, it is cheaper. Professor Köpocke, of Dresden, gives an instance of a train, consisting of thirty-nine trucks, having been divided in twelve groups (for that number of different destinations) in nine minutes, at a cost of 0·0045 franc per train-kilometre (0·00072*d.* per train-mile), whilst in the usual way the cost would have been 0·0092 franc per train kilometre (0·00147*d.* per train-mile). In a report by a commission of inquiry into the working of this system on the railways of northern Germany, it is stated that a saving of about one-half of the time required for sorting is effected by the gravitation plan, as compared with the old system, and a length of rails of 2·64 metres (8·66 feet) is required for the former per truck, against 4·88 metre (16 feet) by the latter, whilst the cost of shunting is reduced from 0·34 franc (3½*d.*) per truck to 0·14 franc (nearly 1½*d.*) per truck at stations where the gravitation system is in use. Statistics given by other authorities show a saving on the average of 28 per cent. in the cost of shunting by gravitation, and that accidents are less frequent where it is in use.

The new goods yard at Milan is 1,200 metres (3,936 feet) in length; the lines of way for the sorting of the trucks being situated on the side of the main line farthest from the city, whilst those for the reception of such merchandise as is not forwarded direct to its destination, and for empty trucks, are laid down on the nearest side.

The lines of rail for starting the trucks by gravitation are two in number, and are 353 metres (1150 feet) in length, with a gradient of 10 per 1000 (1 in 100), which has been found by experience in Saxony to be the most suitable one, and they are laid in such a way as to slope in both directions, that is to say, towards the points of junction with the main line, and towards the sidings for sorting. This gradient is followed by another of 6 per 1000 (1 in 166·66), 185 metres (608·8 feet) in length, and then by a short length of way perfectly level, from which the thirty sidings for

sorting, branch off in the shape of a fan. The starting ways are connected with the others at each end, as also with other lines of rails which serve for the engine traffic; between these lines and the main ones are other eight parallel ways, for the reception of trains waiting to be classified, or already sorted and made up for dispatch. The points are worked by hand, but eventually, as soon as Messrs. Saxby and Farmer's apparatus is completed, the entire operations of changing and sorting the trucks on arrival and departure will be controlled from a single pointsman's box. The goods yard contains a large running shed for thirty-four locomotives, with repairing shops, and various other buildings, consisting of storehouse, offices, &c., and will be lighted by electricity.

P. L. N. F.

The Asphalt Pavements of Berlin. By LÉON MALO.

(Comptes rendus des Ingénieurs civils, February 1885, p. 166.)

In 1876, when the maintenance of the public ways of Berlin passed from the hands of the State into those of the local authorities, there were in that city, 4,476,000 square yards of way; of which 14,400 square yards were of stone pavement laid on sand, in good condition, with 4,018 yards of the same, in bad condition; 432,000 yards of macadam, and 12,000 yards of asphalt. At present there are 450,000 square yards of stone pavement laid on a solid foundation, and jointed with sand and bitumen; 654,000 yards of pavement laid on gravel, in quiet streets, in good condition; 3,705,600 yards of pavement in bad condition, temporarily laid; 579,600 yards of macadam, principally in outlying quarters, and in the Zoological Gardens; 384,000 yards of asphalt, and 48,000 yards of wood pavement.

Ordinary stone pavements are laid in Swedish granite (Karlskrona), excepting some thousands of yards laid in porphyry from Belgium. The blocks are delivered ready for laying, the granites being from 7½ inches to 8 inches in thickness; and the porphyries from 6 inches to 6½ inches thick. According to the usual method of laying, a 4-inch layer of broken granite is deposited on the subsoil, and upon this a second bed of granite more finely divided, also 4 inches thick, which is rolled down under a 15-ton steam-roller. A layer of gravel, about 1 inch thick, is scattered over the rolled bed, on which paving stones or sets are placed half an inch clear of each other; jointed in the intervals with a mixture of pitch and creosote. Under the lines of tramway, whatever may be the superstructure, a foundation of cement-concrete is made. Paving consisting of stone-sets laid on concrete, is not in favour in Berlin.

Wood pavement, of Swedish fir, was first tried on a large scale in Berlin in 1879, laid by the Improved Wood Pavement Company. It has since disappeared, probably for the same reason that

the pavement laid in Paris by the same company was removed after having been down for five years. Though this pavement was laid on a thick bed of cement-concrete, in a street of light traffic, near the Opera, the wood decayed, it wore very unequally, and was converted into mire. Carriages ceased to use the street, in order to avoid excessive jolting. Wood pavements laid by other companies still exist, to the extent of 48,000 square yards, in Berlin; but it is very unpopular, in consequence of the odour of the melted tar which escapes from the joints in summer, and its removal is but a question of time.

Asphalt pavement is extensively laid in Berlin, 384,000 square yards being covered with it, and it is destined to supersede other pavements in all the best streets of that capital. Four different asphalts are used, Val-de-Travers, Seyssel, Ragusa (Sicily), and Limmer (Hanover). The Val-de-Travers asphalt, the first that was laid, tends to become softened in the height of summer under the wheels of carriages, and to form waves, which nevertheless disappear on the return of cooler weather. In Paris, a mixture of Seyssel asphalt with that of the Val-de-Travers, is found to resist that tendency. Ragusa asphalt is open to the same objection; but the Seyssel asphalt, holding a less percentage of bitumen in its composition, is entirely free from softening. It is more difficult to manipulate than the two others, and requires to be very regularly heated for laying; but it is harder and much more durable than these. The concrete foundation, which is from 8 inches to 9 inches in thickness, is laid with extreme care. It is made with an allowance of about 290 lbs. of best Portland cement for each cubic yard of "ballast," procured in the neighbourhood of Berlin, consisting of flint stones mixed with a kind of coarse sand. The asphalt is never laid until the concrete is perfectly set and completely dry—a precaution of prime importance for obviating the formation of steam and the consequent degradation of the asphalt, heated as it is to upwards of 250° Fahrenheit, which takes place when that precaution is not observed, as has been noticed in the earlier attempts of the Parisians in laying asphalt pavements.

D. K. C.

The Naples Waterworks. By NICOLA LAZZARO.

(Le acque di Napoli "L'Illustrazione Italiana, 17 May, 1885, p. 311.")

Until the present time about two-thirds of the population of Naples has been supplied with water from wells, and by two aqueducts called the Bolla and the Carmignano, and the remaining third by several small springs, and by the rain-water collected in a large number of cisterns.

The Bolla aqueduct derives its supply from springs on the northern slope of Monte Somma; it is 7,400 metres (4·6 miles) in length, and delivers on the average 5,200 cubic metres per diem

(1,144,000 gallons). It is of very ancient date, and was probably built by the Romans.

The Carmignano aqueduct, which is supplied by the springs of Montesarchio between the mountains of Taburno and Avella, was constructed between the years 1627 and 1629 by Cesare Carmignano and the engineer Ciminelli. It is 50 kilometres (31 miles) in length, and delivers 30,000 cubic metres (6,600,000 gallons) per day, of which only about one-third is distributed to the population.

The first proposal to supply Naples from the attendant springs in the valley of the Serino in the province of Avellino, was made as far back as 1840, and two different routes were proposed, the first of which being to cross the mountain range of the Serino near Forino and Monteforte, or else to follow the course of the torrent Sabato, and the northern slopes of the Avella mountains, and in both cases to reach Naples by crossing the plain with a reversed siphon. Both these projects, however, necessitated tunnels from 6 to 13 kilometres (3·72 to 8·06 miles) in length, and reversed siphons of considerable extent.

Finally, after a series of difficulties, in which an English company and bank were involved, the *Compagnie Générale des Eaux* of Paris, took up the scheme and commenced the work in 1880, and this was soon afterwards contracted for by the *Societá Veneta di Costruzione*, and the greater part of the cast-iron mains were supplied by the Terni foundry.

The line chosen is considerably longer than that originally proposed, but the long lengths of tunnels and reversed siphons are avoided by its adoption.

The waters from the springs of Orcinoli in the valley of the Serino are collected by means of three infiltration galleries of a total length of 500 metres (1,640 feet), at a depth of 15 metres (49·2 feet) below the surface, the floors of these galleries are not paved, and openings are left in the masonry side walls and arch in order to allow the water to flow in. The galleries were executed in open cutting, and the back of the masonry and above the arches was filled in with loose stones, and the whole covered with a deep layer of puddle in order to prevent the percolation of the rain and surface water. These galleries unite at a large circular tank which forms the head of the masonry conduit. This conduit crosses under the bed of the torrent Sabato, and following on its left bank below the village of Cesinale as far as Atripolda; at this place the torrent Pentarola is crossed by a fine aqueduct 600 millimetres in length (1,968 feet), and 1,700 metres (about 1 mile) further on the Rio Vergine and the Rio Noce are crossed by another aqueduct 800 metres long (2,624 feet).

The next works of importance are the two tunnels of Toppole, one 665 metres (2,181·2 feet), and the other 722 metres (2,368·16 feet) in length, and these are followed by numerous tunnels and reversed siphons to the neighbourhood of Altavilla-Irpina, where the conduit leaves the valley of the Sabato, passing beneath the bed

of that torrent by a tunnel 1,526 metres (5,005·28 feet) in length. The valleys of Tronti and Griudi are crossed by reversed siphons consisting of cast-iron pipes, and the conduit finally reaches the Ciardelli tunnel, 3,161 metres in length (10,368 feet); after passing this tunnel it follows the contour of the ground at the foot of the mountains of Avella to Arpaia, with numerous works of considerable importance, amongst which may be mentioned the tunnels of Pannarano, 836 metres (2,742 feet), Vallo, 517 metres (1,695·76 feet), and that of Arpaia 675 metres (2,214 feet) in length respectively. From Arpaia, after a fall of 30 metres (108·4 feet), the line of conduit is constructed on the northern slope of the Avella mountains, and reaches the hills of Cancello, where it terminates at the pipe-head chamber of the great reversed siphons which convey the water from this point across the plains to Naples. The total length of the conduit in masonry from the springs to Cancello is 59,594 metres (37 miles), of which 13,730 metres (8·52 miles) in tunnel and 1,114 metres (1,018·2 yards) in siphons.

The reversed siphons consist of three parallel lines of pipes; the first 70 centimetres (27·56 inches) in diameter and terminating at the reservoir of Scudillo, 22 kilometres (13·64 miles) in length, and under the pressure of a head equal to 18 atmospheres, from which the upper part of the city is supplied, whilst the other two, which are 80 centimetres (31·5 inches) in diameter, and 20 kilometres in length (12·4 miles), are subject to a maximum pressure of 10½ atmospheres.

The line of pipes are laid in a straight line across the plain, passing to the north of Acerra, between the villages of Afragola and Castelnuovo, to Patierno, where the two 80-centimetres (31·5 inches) mains deliver their water into a masonry conduit 2 kilometres (1·24 mile) in length, which terminates at the great service reservoir at Capodimonte, while the smaller main continues its course to the service reservoir at Scudillo, 2 kilometres (1·24 mile) further.

The reservoir at Capodimonte is capable of containing 80,000 cubic metres (17,600,000 gallons) of water, and consists of five parallel chambers, each 250 metres (820 feet) long and 10 metres (32·8 feet) in width, tunnelled in the tufa, and 10 metres (32·80 feet) apart, and form three independent reservoirs, each outer pair of galleries being in communication with the other by means of cross cuts. These five chambers are provided with an overflow placed at such a height above the bottom, so as to maintain a maximum depth of 8½ metres (27·88 feet) of water in them. At right angles to these chambers are three small galleries, situated in the same vertical plane, but at different levels. The upper one, which is at the level of the overflow, communicates with the masonry conduit, and it is by this that the water enters the reservoirs, and means are provided for regulating its flow into them. The middle gallery is situated at the level of the floor of the reservoir, and contains the two principal cast-iron mains, by which the water is supplied to the city from the three reservoirs, its flow in them

being regulated by suitable valves; the valves for discharging the reservoirs into a channel in the gallery beneath are also controlled from the middle one. The overflow also is conducted into the lower gallery which is in communication with the great sewer Dei Vergini, and the surplus water in this way is discharged eventually into the sea.

The service-reservoir at Scudillo consists of three similar galleries excavated in the tufa, and is capable of containing 20,000 cubic metres (4,400,000 gallons) of water.

P. L. N. F.

Water-Supply of Venice. By B. Fineti.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 25 April, 1885, p. 163.)

Until 1884 Venice was supplied with water from cisterns and reservoirs (one hundred and eleven public and one thousand eight hundred private) which had been in use since the fifteenth century. These only gave a supply of 1¾ gallon, increased by water brought in boats to 2·2 gallons daily per head. Experiments in Artesian wells conducted during the last forty years have not been successful. In 1876 arrangements were made for the construction of works for an entirely new water-supply, to consist of an aqueduct from the River Brenta and an Artesian well with a minimum diameter of 1 foot. The aqueduct is now completed. Leaving the Upper Brenta at Stra the water is taken by a canal about 13 miles long to Moranzam, where there is a surface sand-filter of 1,464 square yards area and a turbine- and pumping-station for lifting the filtered water. Cast-iron pipes 31½ inches diameter convey the water a distance of about 4 miles to a reservoir of 353,166 cubic feet capacity, which is within the town. From this it is distributed over the city.

The filters consist of four basins each with an area of 388 square yards. The supply canal which surrounds them has an arrangement at the overflows by which the filter water is kept in motion, and its freezing or the growth of water-plants is thus prevented. The pipes from the pumping-station cross the lagoon and are laid for about 2½ miles under water. The laying of these pipes was a work of some difficulty, involving cofferdams 16 feet deep, the badness of the foundation causing much trouble. The water was kept out of the cofferdams by centrifugal pumps worked by floating engines.

In the lagoon and on the land the canals for navigation are crossed by siphons, the most important of which is 142 yards long. Another one has a fall of 23·5 feet; this as an exception is of wrought iron 3·28 feet diameter; its bed was dredged between sheet-piling.

The pipes were laid by divers, and are embedded in concrete. In

the lagoon there are sixteen cast-iron air- and entrance-shafts. The reservoir in Venice has an area of 2,392 square yards, and a water depth of 16·4 feet; its bottom is 6·6 feet below sea-level.

The water is forced into the mains by two condensing-engines of 25 HP.; 16½ miles of mains were laid in 1884.

The crossing of the canals, some of which are 76 yards wide, is effected either by taking the pipes over the bridges—in which case they have a flattened cross-section—or by means of siphons with vertical rise and fall, amounting in some cases to 23 feet, passing under the canals. When this is done the pipe passes down the back of the quay-wall, under the foundation and out between the piles on which the wall is built. There are forty-five cases of the former method and forty-six of the latter.

The quantity of water now provided is 11 gallons per head per day for a population of 130,000, at a cost of about £1,600 per annum more than the old supply of 2·2 gallons per head.

The Artesian well had in the spring of 1884 reached a depth of over 650 feet, which has since been increased.

W. B. W.

Underground Water Courses and the Means of Utilizing them.

By Professor MICHELE CAPITO.

(Giornale del Genio Civile, 1884, p. 589.)

When rain falls, that portion of it which is absorbed by the ground passes down through permeable strata or through cracks and fissures till it reaches an impervious surface, upon which it flows in channels, which are determined by the configuration of this surface, forming, as it were, subterranean streams and rivers. Large volumes of water are also stored up in cavities and in water-bearing formations which help to maintain the flow in the streams.

In mountainous districts, when the surface formations are permeable and overlie impervious beds approximately parallel to the surface, a stream of underground water will generally be found in each valley; when, however, the upper and lower strata are not parallel, the course of the underground water will be more difficult to find. The Abbé Paramelle states that the most likely places for finding a good supply of water in such districts are: (*a*) the point at which all the streams forming the commencement of the *thalweg* unite, which is easily found, as it lies towards the middle of the valley in which the thalweg begins to appear; (*b*) each principal change of gradient as the surface stream becomes less steep, for at these points the underground water rises nearer to the surface in order to obtain a greater head, and so maintain its velocity, notwithstanding the fact that the accelerating forces are diminishing; (*c*) the points at which tributaries join the main stream. It frequently happens that when the surface stream is dry in summer

a good flow of water will be found below the surface. The more or less vigorous vegetation is often an indication of the comparative depth of which the underground water runs.

When a spring issuing from the ground in the neighbourhood of a stream varies in volume as the latter rises and falls, it does not follow that the water of the spring is derived from the stream. After a flood the volume of the underground water is increased, and the springs are headed back, and as it flows away the springs resume their former condition. The same thing happens daily with springs that flow into a tidal sea, they being similarly headed back by the flood tide.

The study of the flow in underground channels presents serious difficulties. Very little is known of the impermeable stratum which forms their bed, or of the various obstacles which interfere with the flow. The Author deals with the methods of utilizing water which flows through a permeable stratum denuded at the surface, or between beds of marl or clay of limited thickness.

When the bottom of the subterranean canal can be intercepted at a higher level than the point at which the water is required for use, it may be obtained by driving an adit. When the underground stream is somewhat lower than the point at which it is required for use, an underground dam may be constructed to raise the level of the water to the necessary height. When the water is at too great a depth to be obtained by either of these methods, it becomes necessary to sink wells and establish pumps. In the first case the adit should not only be driven to the bottom of the channel, but to a point where the bottom is greatly depressed (which must be ascertained by trial), in order that a good supply may be obtained in dry seasons. To ascertain the yield of the stream a well may be sunk through it and continued a short distance into the impermeable stratum, and a pump erected. Now let the time t be noted in which the water can be lowered from its normal level to the impervious surface. The volume Q of water raised will consist of a part V contained in the well itself and the interstices of the permeable ground, and another part $q\,t$ which has flowed in during the time t, hence

$$Q = V + q\,t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The water is then to be allowed to rise to its normal level, and a second pump set to work. The time taken to lower the water to the impervious stratum will be $t' < t$. In this time t' a volume Q′ of water will be raised, consisting of V as before, and qt' the yield from the stream,

$$Q' = V + qt' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

from which can now be found q, the yield of the stream per unit of time, for, subtracting (2) from (1), we have $Q - Q' = q\,(t - t')$, whence $q = \dfrac{Q - Q'}{t - t'}$.

In regard to wells the Author states that he considers the best method of dealing with those cases in which the water-level varies to such an extent that the pumps must be either sometimes drowned or sometimes unable to draw the water, is, after having sunk one well, to sink a second near it with an adit between the two. The second well should be steined with a watertight lining, and the pumps placed in it at such a depth that they will draw water from the lowest level. The admission of water from the first into the second well can be regulated by means of sluices.

The Author then proceeds to the question of underground dams. These may be constructed either for the purpose of intercepting the whole of an underground stream without raising its level, or for raising the level also. The latter process may fail, owing to the water when raised above its normal level finding new channels by which it can escape. Great care is therefore necessary before commencing such a work in examining the surrounding country in order to ascertain as far as possible the extent of the impervious stratum, and to discover if any signs of outlets for the water are discernible. There will, however, always be a certain amount of risk attending this operation. In most cases it is better to go up the valley to such a point (if there be one) as will allow the water to be intercepted above the level at which it is to be consumed, and to convey it from the dam in an open channel or in pipes. A combination of an underground dam with a pumping station will in some cases be the best solution of the difficulty.

In 1881 the Author was called in to advise respecting the water supply to the Commune of Trabia, which is situated on the sea shore at the foot of some hills. Certain springs issue from a valley near the village, and some time previously an attempt had been made to increase their yield by the construction of a dam across the valley. As however the foundation of this dam was not carried down to an impervious stratum, the effect of it was that the water escaped underneath it. Upon a careful investigation the Author found that in addition to the surface springs there was also an underground channel, and a series of trial holes, and the information he obtained as to foundations of houses, &c., led him to the conclusion that there was a bed of clay lying under the valley, and that by constructing a dam with foundations upon this bed he would be able to dam up the wall to a convenient height. A dam about 800 feet long was accordingly built, consisting of two limestone walls three feet apart, the interval being filled with hydraulic concrete. Great difficulties were found in excavating the trench of the dam owing to local circumstances, but these were successfully overcome. No pumping was required, it being found practicable to drain away the water from the trench. Culverts were built at the lowest levels of the valley by means of which the water can be released from behind the dam so as to prevent the permeable strata from being filled up by deposits. A detailed description is given in the paper of the progress of the work. The

cost was about £8,000, and the result was that even during the drought of last year the yield of water was 42 gallons per second, as compared to 24 gallons in 1881.

W. H. T.

A new Apparatus for determining the relative purity of the Atmosphere in Habitations.

(Gesundheits-Ingenieur, No. 8, April 30, 1885, p. 221.)

The estimation of volume of carbonic-acid gas it contains is at present the only experimental method of judging of the condition of the air in enclosed areas, and therefore it is important, from the sanitary point of view, to possess an easy and rapid method of ascertaining the amount of this gas present in the atmosphere. Several plans have been proposed for this purpose, all of which are based on the milkiness produced by this gas in a colourless solution of lime or baryta, and therefore on a qualitative appearance, which was not directly connected with the amount of the gas actually present. The new apparatus, devised by Dr. R. Blochmann, possesses the merit of giving quantitative results and of being so simple in its action that no chemical knowledge is required in order to use it; it is also very cheap. The process is based on the employment of a sufficient volume of the air under trial to saturate, by means of the carbolic-acid gas present in it, a given amount of lime-water. In order to recognize the fact of this saturation a few drops of phenolphtaleïn are added to the lime-water, until it assumes a visibly red tint. The colour remains as long as the liquid remains alkaline, but directly the caustic lime is all converted into the carbonate, a very small excess of carbonic-acid is sufficient entirely to destroy all trace of the red tint. A description of the apparatus is given, and the mode of using it is as follows:—A bottle is filled with the air to be tested by sucking out the air contained in it through a bent glass tube; a measured quantity of lime-water is added to the bottle, together with three drops of solution of phenolphtaleïn, and the bottle is then corked and shaken for three or four minutes; if the liquid is still red the bottle is filled a second time with air, corked and shaken as before, and the process is repeated until the colour in the liquid vanishes. If the colour remains for eight fillings, the air is good; if it disappears at or before the sixth filling, it is on the borders of what sanitarians consider to be fitted for breathing; if the colour goes at the third filling the air is so impure as to render it wholly unfit to be breathed. A Table follows comparing this method with the results obtained under the exact system of Pettenkofer showing this process to be very accurate, and in a second Table the parts of carbonic-acid gas present in 1,000 volumes of air given, as indicated by the results of each filling—from one to twelve. Thus, taking 1 measure of lime-water equals

one filling, 6 volumes of carbonic-acid gas per mille equals three fillings; 2 volumes of carbonic-acid gas per mille equals three fillings; 1·0 volume of carbonic-acid gas per mille equals six fillings; 0·50 volume of carbonic-acid gas per mille equals twelve fillings. By increasing the quantity of lime-water, the presence of much larger volumes of the gas can be ascertained; thus with 4 measures of lime-water a discoloration at the first filling would imply the existence of 23 volumes of carbonic-acid gas in 1,000, or at the tenth filling, 2·3 volumes per mille.

G. R. R.

The Danger of the Service of Natural Gas under High Pressure.

(Gesundheits-Ingenieur, No. 8, April 30, 1885, p. 233.)

Attempts have recently been made in Pennsylvania to regulate and bring under control the supply of natural gas, though as yet with no results of importance. The gas is entirely devoid of smell and is passed into the mains at the high pressure of 3·5 kilograms per square centimetre (49·7 lbs. per square inch). It would be deemed risky to deliver such gas into the house connections under ordinary pressures, but at such a high pressure as this the danger is far greater, and yet owing to the advantages and convenience of the smaller service-pipes required, these risks are encountered in certain American towns, as for instance in Pittsburg. In a large glass works natural gas is supplied under the boiler in a $\frac{3}{4}$-inch pipe, while in a similar factory, where common gas is employed, a 6-inch supply-pipe is needed to produce the same effect. This difference, however, is not wholly due to the high pressure at which the natural gas is delivered, for in the latter case a mixture of water-gas and gas-produce gas is used, which has a smaller calorific value than the natural gas. That the dangers are not of an imaginary character is proved by three disastrous explosions which have lately taken place there, by which several persons have been seriously injured, and great damage has been done to property. Details of these accidents are given. They appear to have been caused by leakages in the pipes and the accumulation of gas in cellars.

G. R. R.

Water-Gas.

(Gesundheits-Ingenieur, No. 11, June 15, 1885, p. 331.)

Water-gas will shortly be utilized both for heating and illuminating purposes. This matter has passed beyond the experimental stage, and the European Water-gas Company have introduced their gas for both purposes into the works of Messrs. Schultz,

Knaudt and Company of Essen. The problem of the economical production of the gas has also been solved, and the process adopted by them is as follows:—Superheated steam and air are forced alternately through a mass of glowing coal. The products, when steam is used, being conducted to the gas-holder and, when air is employed, being passed into the chimney. The temperature sinks so rapidly, when the steam is being driven through, that the fuel in a short time fails to decompose it, and it becomes necessary to revive the combustion by the admission of air. The generator employed at Essen is a cylindrical vessel of five lamps surrounded with a case of iron boiler-plates. This rests at the point where the air is admitted, upon a ring, kept cool by water. Beneath this ring the air can be forced in by means of a fan. The coal is introduced at the top. By the side of this gas-producer are two other cylindrical regenerators made of boiler-plate, lined with fire-lamps, and through these when air is being blown in the products of combustion are allowed to circulate. The completely burned gases pass from the upper part of the generator into the first regenerator from the top to the bottom, in the second from the bottom to the top, and from thence escape into the chimney. When the air is turned off, the steam is admitted in the reverse direction, passing first into the regenerators, and abstracting from them their heat. The fuel employed at Essen for the generator consists of the cinders from the puddling and other furnaces, which after having been washed contain about 50 per cent. of coal. When the supply of cinders is insufficient, coke breeze is employed.

The following is the process adopted:—When the inrush of steam has cooled the fuel to a dull red heat, the man in charge of the apparatus turns a hand-wheel, which cuts off the supply of steam and closes the pipe leading to the gasometer, but simultaneously opens the valve for the admission of compressed air and the outlet flue to the chimney. The fire at once bursts forth into fierce combustion, and the gases also, at their exit from the upper part of the generator, encounter a stream of air, blown in through a tube, which completes the combustion, the flames passing through the regenerators into the chimney. As soon as the fuel has been brought into vigorous combustion the attendant turns back the wheel, and by this means reverses the draught, cuts off the air and admits the steam. As, however, the generator and the two regenerators will be full of the products of combustion, steam is allowed to blow through until these gases are expelled, when the valve communicating with the gas-holder is opened. The process has been in operation for a year, during which time no difficulties have arisen. The admission of steam lasts for five minutes, the air-supply requiring ten minutes; there are thus eight changes per hour. When the gas is required only for heating purposes no purification is needed; when used for lighting or for gas-machines it has to be purified by passing it through oxide of iron. The gas at Essen contains about 90 per cent. of

combustible material, viz., about 50 volumes of hydrogen, and 40 of carbonic-oxide, together with 5 volumes of carbonic-acid, 5 of nitrogen, and a little superheated hydrogen. The gas burns with a blue flame and gives out an intense heat. In order to render it suitable for illuminating purposes, attempts were at first made to enrich it with heavy hydro-carbons, but the best results have been obtained by the introduction into this flame of bodies capable of resisting a white heat, on the principle of the Siemens burner. After many trials it has been found expedient to employ little rods of magnesia kneaded into a paste with india-rubber, and pressed through a small aperture into threads about ¾ of a millimetre in diameter. These threads are then exposed to intense heat in a gas-furnace and fused with hard porcelain-like pigments. They are then formed into a burner by inserting them in a double row into a metal-holder, in a similar way to the teeth of a comb. This holder is fixed above an ordinary gas-burner, and, a few seconds after the gas is lighted, a brilliant white light is produced. The magnesia is gradually consumed, but a burner will last for about eighty or one hundred hours, and can be supplied by the company complete and ready for use for twenty pfennings (2*d.*). The cost of the installation complete, including a gas-holder costing £1,000, has amounted to £2,100. Each kilogram of fuel yields about 1 cubic metre of gas, and taking the price of the fuel at five marks per ton, with an allowance of 15 per cent. for interest and sinking fund, the cost of the gas is about one pfenning per cubic metre (3*s*. 3*d*. per 1,000 cubic feet).

G. R. R.

Steam Automotor for Small Industries. By ABEL PIFRE.

(Comptes rendus de la Société des Ingénieurs-civils, 1885, p. 315.)

The Author, referring to the results of his labours in 1880, relative to the utilization of direct solar heat, was led by them to the improvement of the machinery of small industry in France. He has designed a steam-motor, which he has baptized "automotor," signifying that it may work without such special supervision for a sufficient length of time, as entails expenses of attendance out of proportion to the work done. The apparatus consists of the generator, the motor properly so called, and the condenser. The generator is vertical, like an ordinary close heating stove, having a lid which closes the opening in the top, by which the fuel is charged into an internal hopper, which descends until it reaches a convenient distance above the grate. The grate is placed at the bottom on an ash-pit provided with an air-slide. The stove is sufficiently charged with fuel to last several hours, combustion taking place only at the bottom of the hopper, in a continuous and regular manner. The motor, or engine, also, is vertical, of the steam-hammer type, on one base with the generator. The cylinder

is of bronze, with pistons and valves of a special metal compounded by Mr. Pifre, like anti-friction metal. No other lubrication is necessary than that supplied by the steam passing through the engine. The condenser is a surface-condenser.

The boiler is filled with water to the required level, shown by a gauge-glass; the fire is lit with wood on the grate, as the ordinary stove is lit, and the hopper is charged. The steam produced passes into the cylinder for work, and the condensed steam is pumped into the boiler. In case the pump fails to act, an alarm-whistle is sounded through the medium of an electric float in the feed-box. The whole of the condensed steam is returned to the boiler as feed-water, and the only fresh supply of water is that which is required to supply losses by leakage.

Automotors of ¼ HP., ½ HP., 1 HP., and 2, 3, and 4 HP. have been constructed. The boiler for ½ HP. is half a metre, or 19½ inches in diameter, and the heating surface is at the rate of 13½ square feet (1¼ square metre) per HP. The fire-grate is 1·95 square foot in area. As the result of many trials, the minimum consumption of steam has been found to be at the rate of about 60 lbs. of steam to produce 1 HP. per hour. The weight of a ½ HP. automotor is 1,210 lbs.; 1 HP., 1,430 lbs.; 2 HP., 2,530 lbs. The fire is regulated by the ash-pit door, or by the damper in the chimney. A 1 HP. engine consumes 2¾ bushels of coke, including getting up steam, in 10 working hours, and with a mid-day interval of rest, being at the rate of about 11 lbs. per HP. per hour. An automotor of 4 HP. consumes about 5¾ bushels for the same period, being at the rate of about 4½ lbs. per HP. per hour. Steam is got up in 20 minutes. With ordinary coal as fuel, it is necessary occasionally to loosen the pieces, which are apt to cake, in the hopper; and the lid must be hermetically closed to prevent the escape of fumes.

The boiler is constructed with vertical tubes. Tubes nearly horizontal proved to be defective for circulation. Incrustation in the tubes is nearly impossible; the circulation is rapid. For the surface-condenser, when placed near the stove, 60 gallons of water per hour are consumed for a 1 HP. engine, 111 gallons for 2 HP., and 155 gallons for 3 HP. But, by employing exhaust-pipes from 80 to 100 feet in length, laid along the wall, the whole of the exhaust-steam arrives at the far end as water.

D. K. C.

Test of a Portable Engine. By H. Walther-Meunier.

(Bulletin de la Société Industrielle de Mulhouse, April–June, 1885, p. 269.)

A report of a test of a portable engine, conducted by Mr. Walther-Meunier, is embodied in his general report to the Alsatian Association of Proprietors of Steam Boilers, for 1884. The engine was constructed by Messrs. Quiri and Co., near Strasburg. The

boiler is of the Thomas and Laurens system, having an internal furnace with return-tubes. The engine is horizontal, and is fixed on the top of the boiler with which the steam-jacket is in free communication. It is fitted with Ryder's governor, and is non-condensing. The area of fire-grate is 5·06 square feet; there is 183 square feet of heating surface, or 36 times the area of grate. The cylinder is about 9½ inches in diameter, with a stroke of 14 inches. The piston rod is 1·57 inch in diameter.

The trial lasted seven hours, with an average speed of 110·95 revolutions per minute; with a performance of 23·77 I.HP., or 19·87 brake HP., showing an efficiency of 83·6 per cent. An average pressure of 111 lbs. per square inch was maintained, Louisenthal small coal was used, at the rate of 73·3 lbs. per hour, or 14·35 lbs. per square foot of fire-grate per hour. Water was evaporated at the rate of 931 lbs., or 14·92 cubic feet per hour, from the temperature 68° Fahrenheit, or 9·21 lbs. per lb. of coal, equivalent to 10·92 lbs. from and at 212° Fahrenheit. There was 6 per cent. of ash and clinker. Steam was consumed at the rate of 28·47 lbs. per I.HP., and coal at the rate of 3·05 lbs. per I.HP.

The engine was tested for efficiency, or percentage of brake-power in parts of indicator power for various indicator powers. A selection of corresponding powers are here given:—

Turns per Minute.	I.HP.	Brake HP.	Efficiency. Per cent.
115·60	0·235	0·000	..
115·40	1·601	1·047	65·4
114·33	7·069	5·196	73·5
113·25	13·390	10·284	76·8
112·00	20·189	16·2 3	80·6
119·00	27·763	23·974	86·3

D. K. C.

A Bulged Boiler-plate.

(The American Engineer, April 17, 1885.)

The *Locomotive*, in its March issue, illustrates and describes the bulging out of the bottom plates of a steam-boiler, due to the putting in of black oil after cleaning. The metal, originally $\frac{5}{16}$ of an inch thick, drew down to $\frac{1}{8}$ of an inch in thickness at the lowest point of the "bag," without the slightest indication of fracture. The action is explained by the settling down of the grease on the fire sheets, when the draught is closed, and the circulation nearly stops, and thus preventing contact between the plates and the water. As a consequence, the plates over the fire become overheated. The *Locomotive* maintains that the thinnest possible coating of the varnish of the boiled grease on the plates is sufficient to bring about overheating of the plates. The use of pure mineral oil does not produce this dangerous varnishing, but black oil does. The accident in question serves to illustrate the

perfection to which the manufacture of steel for boiler-plates has attained; it would be an extraordinarily good quality of iron that would stand such a test without fracture.

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Steam-Boilers at the International Electrical Exhibition, 1884.

(The Journal of the Franklin Institute, July 1885.)

The Report of the Examiners in Section X. (Steam Boilers) of the International Electrical Exhibition, held at Philadelphia, in 1884, has been published as a supplement to the above-named journal. Four boilers were presented for testing, the Root boiler, the Harrison boiler, the Dickson boiler, and the Baldwin boiler. The first boiler is tubulous in structure, and the second is sectional, of cast-iron spheres, enveloped in brickwork. The third is a boiler of the locomotive type, having a cylindrical shell 50 inches in diameter and 34½ feet long, with sixty-eight 3-inch tubes, 15 feet in length. The fire-box is wider at the bottom than at the top.[1] There is a steam-dome 30 inches in diameter, and 30 inches high. The firegrate is of the How pattern, 6½ feet by 4 feet 10 inches. The boiler was covered with a 1-inch layer of felt. The boiler was designed for burning culm, but screenings from pea-coal were used instead. It appears by the illustrations that the ashpit is closed, with a forced draught by steam-induction, but there is no mention of this system in the report. The Baldwin boiler is a horizontal cylindrical boiler, 54 inches in diameter, and 16 feet long, having thirty-two tubular flues 4 inches in diameter. Above the boiler a 24-inch steam-drum, 8 feet long, is placed, connected to it by means of one neck 12 inches in diameter and 10 inches high. The firegrate is placed at a level 34 inches below the boiler. The firebars are about 3 feet in length; the bridge is about 15 inches from the end of the grate and is connected to it by a sloping floor of brickwork. Beyond the bridge, near the end of the boiler, there is a transverse partition of brick, with numerous loopholes, to give passage to the burnt gases. From the illustrations it appears that air is blown into the furnace from above the door by means of jets of steam; but there is no mention of this appliance in the report. The whole of the boiler is enveloped in brickwork.

The boilers were tested for performance only. Steam was first raised to the working-pressure in each boiler, and the fires were then drawn. Wood and coal used subsequently were weighed out, and at the end of the test, the fire was drawn, and the unburnt coal was credited to the boiler. The water-level in the boiler was maintained as nearly uniform as possible, and at the end of the

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[1] It is stated by mistake in the Report that the fire-box is wider at the top than at the bottom.—D. K. C.

test, it was brought to the same level as at the beginning. The coal used in the tests was purchased at different times, and was supplied to the sizes desired by the several exhibitors. The coal was analyzed from time to time, and the average percentages of carbon and hydrogen were for the several boilers as follows:—

		Per cent.		Per cent.
Root	Carbon	75·52	Hydrogen	2·18
Harrison . . .	„	75·21	„	1·82
Dickson . . .	„	72·87	„	2·53
Baldwin . . .	„	80·22	„	2·53

Wood, as fuel, was reckoned as equivalent to one-fourth of its weight of coal.

The general results of the tests of these four boilers are given in the following Table:—

Name of boiler	Root.	Harrison.	Dickson.	Baldwin.
Duration of trial . . . . hours	36	36	36	24
Nominal horse-power . . . HP.	150	100	76	50
Developed HP., assuming 30 lbs. of water from and at 212° per HP. . . . . HP.	148·3	101·9	147·0	63·5
Water heating-surface . sq. feet	1,440	948·54	841	663·31
Steam heating-surface . „	360	348·96	2·50	136·31
Total heating-surface . „	1,800	1,297·5	843·50	799·62
Grate-area . . . . . . „	50	35·13	31·41	21
Ratio of grate-area to heating-surface	1 to 36	1 to 37	1 to 26·8	1 to 38
Height of chimney above grate feet	44·5	44·5	28·6	44·5
Average pressure of steam per square inch . . . . . lbs.	91·4	95·8	83·5	98·7
Barometer . . . . inches	30·3	30·3	30·3	30·3
Temperature of the air . . Fahr.	57	57·8	50·3	45·3
Do. in chimney . . . „	369·9	411·0	422·7	346·9
Do. of feed-water . . . „	71·6	68·8	67·2	59·9
Coal and wood per hour . . lbs.	468·9	328·0	557·8	253·2
Do. do. per square foot of fire-grate . . . . . „	9·4[1]	9·3	18	12
Ash per hour . . . . . . „	74	41	140	27
Do. per cent. of coal . per cent.	15·8	12·5	25	10·7
Feed-water per hour . . . lbs.	3,748	2,572	3,810	1,588
Do. per pound of coal . . „	7·99	7·84	6·75	6·27
Do. do. from and at 212° Fahrenheit . . „	10·43	11·23	9·45	8·26
Do. per square foot of grate per hour . . . „	87	89	140	76
Do. do. heating surface per hour . . . . „	2·3	2·5	5·2	2
Draught in chimney . . . inches	0·7 blower	0·24 natural	0·15 steam-jet	0·43 natural
Steam-power in boiler	7·65	29·8	67	..

[1] Marked 10 in the original.—D. K. C.

The large proportion of "ash" weighed from the Dickson boiler—25 per cent. of the coal used—is due to the considerable

quantity of pea-coal siftings which fell into the ashpit, and was thus saturated with the water precipitated from the steam-jets. No attempt was made to burn the refuse a second time.

D. K. C.

The Wery Chimney. By — Pihet.

(Bulletin de la Société d'Encouragement, April 1885, p. 185.)

In the chimney devised by Mr. Wery for the prevention of smoke and economy of fuel, the specialty consists simply in mixing with the burnt gases from the furnace a certain quantity of air relatively cold. The air penetrates the hot current in the manner of the Giffard injector, entering the chimney through a narrow circular opening all round the chimney near its base, proportioned in area to the section of the chimney. The current of cold air envelops the current of hot gases, mixes with it, lowers the temperature, and reduces the draught.

Without endeavouring to analyse the phenomenon, the results of comparative trials made in December 1884, with a 12-HP. portable engine, proved that smoke-prevention was effected, and the fuel economised, by the Wery chimney. The preliminary experiments, one made with the new chimney and the other with the ordinary chimney, gave results very favourable to the new chimney. The engine and boiler, worked by a friction-brake, were proved to be in good order; the steam was exhausted direct into the atmosphere, the natural draught in the chimney alone being in action. The experiments were repeated a fortnight later, burning coal in moderate-sized pieces, with the following results:—

	With the Wery chimney.	With the ordinary chimney.
Duration of trial	4 h. 17 m.	4 h. 16 m.
Coal consumed	235·4 lbs.	305·8 lbs.
Water evaporated	2271 lbs.	2271 lbs.
Water per pound of coal	9·65 lbs.	7·43 lbs.
Horse-power at the brake	11·86 HP.	11·86 HP.
Temperature at the base of the chimney	455 F.	518 F.

Smoke was completely prevented. The time lighting and getting up steam was less with the Wery chimney. The economy effected was 23 per cent. of fuel.

These results are corroborations of like results of trials made by Messrs. Mékarski and Banderali on two Thomas-and-Laurens boilers, and at Fives Lille.

D. K. C.

Non-conducting Coverings for Steam-Pipes.

By Professor J. M. Ordway.

(Transactions of American Society of Mechanical Engineers, vol. v., 1884, p. 212, and vol. vi., 1885, p. 168.)

It having been suggested in the course of the discussion upon the former Paper,[1] that tests of short lengths of pipe, such as those made use of by the Author, would give erroneous results, and that the best tests of coverings would be on lengths of 50 or 100 feet of steam-pipe, in which the water of condensation could be collected and measured. Moreover, that operations on a small scale by the calorimeter, and air-chamber methods would require corrections, owing to the fact that the covering extended beyond the ends of the testing apparatus, some further experiments were undertaken on lengths of 30 feet, and 2 feet of covered pipe, carrying steam at 65 lbs., and on 2½, 5, and 10 feet of blind pipes, with proper arrangements in all cases for collecting the condensed water. It was ascertained that in blind pipes the condensation in the 10-feet length was approximately four times as much as in the 2½-feet length. The determinable condensation in the transmitting pipes was found to be anomalous, and by no means proportionate to the lengths. It was evident that the water formed does not all find its way into the pockets provided, and that moving steam must carry forward not a little mist. Before placing much reliance upon tests obtained in this way, it was deemed expedient to provide means to ascertain the quality of the steam in the pipe. For this purpose small cocks were screwed into the fittings in three places, and to them were attached spiral coils of brass tube of $\frac{1}{12}$ inch bore, open at the end. Each of the coils was enclosed in a calorimeter of about 12 litres capacity. Starting with a weighed quantity of cold water in the calorimeter, steam was allowed to blow in for about three minutes. From the temperature of the steam, and the increase of the water in weight and temperature, it was easy to calculate the percentage of mist in the steam. In many trials the steam was found to be dry; in others the proportion of mist ranged from 2 per cent. to 42 per cent. of the whole. This priming of the steam comes on unexpectedly, and may last but a short time, but still quite long enough to vitiate any determination of the lost heat based on the latent heat of the supposed steam. Other sources of inaccuracy, such as the loss of water in vapour, owing to its being drawn off at a temperature above 100° C. are discussed.

The Author also carried out experiments to test the relation between the condensation that occurs when the heat is transmitted to the air, and that which takes place when the covering is surrounded by water in the calorimeter, and he explains the apparatus he employed. His tests went to prove that the radiation into air

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[1] Minutes of Proceedings Inst. C.E., vol. lxxv., p. 370.

and that into water are nearly identical. He is confirmed in his belief that the calorimetric method of the testing gives the most reliable results. Some new coverings were employed, and an excellent one, consisting of cork chips cemented together and coated with water glass, is described.

He also investigated, in a special apparatus he had devised, the effect of greater or less compression upon the materials used for coverings, as effecting their transmissive power. These materials were used in a uniform thickness of 25 millimetres. A table is given of the kilogram-centigrade heat-units transmitted per hour, varying from 36 for fine table salt to 4 for compressed wool. In the case of the latter material, loose wool ranks as 5·3, ditto, compressed, 4·0, and when still more compressed 4·5; showing that, while moderate compression enhances the non-conductive power, the limit is soon reached when further compactness does no good.

In a third paper the results are given at greater length of the investigations undertaken on behalf of the Factory Mutual Insurance Companies, summarised in the foregoing abstract, the experiments deal chiefly with the points raised upon the discussion of the original Paper, but a large number of substances capable of being employed as pipe-coverings, were examined, and numerous diagrams of apparatus employed, together with Tables of the results of experiments, are appended. The Author sets forth as the outcome of his further investigations:—

(1) Trials of steam-pipe coverings by the method of condensation, are liable to errors on account of the not infrequent priming of steam, which may occur at any time of day. It is also difficult to draw off, without loss, the water that is condensed.

(2) Some method depending on a constant temperature in the pipe, which can be looked to at any time and all times, is preferable to one dependent on the dryness of steam, which is a matter that cannot be constantly watched.

(3) The transmission of heat into the water of a calorimeter does not differ materially from that into free air.

(4) The calorimetric method is preferable as being adapted to running pipes, and not requiring any special arrangement of side branches.

(5) It is useless to make the testing apparatus of cumbrous dimensions, for, as in chemical analysis a grain or less of the sample, instead of kilograms is used, so in physical experiments, increase of size does not necessarily enhance the accuracy of the results.

(6) Air-chambers in pipe-coverings are not advantageous, but it is better to fill hollow places with some light powder.

(7) Compression lessens the actual efficiency of loose powders, or fibres, by diminishing the thickness of the covering.

(8) Of all the substances tried, the most advantageous are hair-felt, cork, fossil-meal, magnesia, charcoal, and rice-chaff.

G. R. R.

New System of Towage for Ship-Canals.

(Le Génie Civil, vol. vii., 1885, p. 180, 1 plate and 3 woodcuts.)

The navigation on ship-canals has hitherto been carried on by means of the engines of steamers, or by the aid of tugs for sailing-vessels. This system presents inconveniences which are increasingly felt in proportion to the growth of traffic such as has occurred on the Suez canal. Thus, although steamers have been limited to a speed of 6 miles an hour on the Suez canal, the motion of their screws causes eddies which injure the slopes and necessitate constant dredging. Moreover the slow progress imposed on vessels built for great speeds, renders their handling very difficult, and is liable to entail accidents. Also at night and during fogs the navigation is interrupted; and slow-going vessels retard the progress of all those that are behind them. Accordingly Mr. Languet, a ship-owner, proposes to remove these inconveniences by introducing a modified system of cable towing, with special reference to the Suez canal. It consists of two strong copper, or brass, wire cables, sunk from end to end of the canal, for vessels towed in each direction respectively. The cables are anchored at each end of the canal, and are connected together at each extremity by a loop, taking a wide sweep, round which the tug can turn; the fastenings being temporarily undone for the passage of the tug. Two kinds of trains can be formed; one for rapid progress, consisting of a single large vessel in the centre, with a tug in front and a brake-tug behind; and the other, going at a lower speed, consisting of a train of vessels similarly preceded and followed by a tug. The tug in front carries two tow ropes for regulating the direction of the vessels in tow; and the brake-tug is similarly provided, together with powerful brakes, its object being to regulate the speed, and if necessary stop the vessels. Twelve enlargements, or sidings, on the canal would enable a quick-going vessel, overtaking a train of slow-going vessels, to take their place between the foremost tugs, the slow train being relegated to the space between the hinder tugs. Mr. Languet considers that by dispensing with the motion of the screws of the large steamers, the speed on the canal might be increased to 8⅔ miles an hour. The power required for a tug to tow a vessel of 40-feet beam and 23 feet draught, at the above speed, would be 392 HP. By this system the passage of vessels through the canal would be both quicker and more regular; and the navigation, being rendered more secure, could be conducted at night and during fogs. Mr. Languet considers that from two to three times the number of vessels could be passed through the canal that go through at present, rendering the proposed enlargement unnecessary. The estimated cost of the enlargement is £8,000,000; whereas the estimate of the establishment of the proposed system of towage, with its necessary sidings, amounts to only one-fifth of this sum. In order to check the wave

raised by vessels in passing quickly through the canal, Mr. Languet proposes to attach a long narrow iron raft, with a deep vertical plate-iron keel, on each side of the vessel.

L. V. H.

Steamboat-Shafts. By H. W. Baker.

(Journal of the Association of Engineering Societies, May 1885, p. 255.)

The paddle-shafts of the stern-wheel boats on the western rivers of America are troublesome from the great number of breakages to which they are subject. So prevalent are the failures of these shafts that it has become a settled conviction that they are inevitable. The Author enters into a detailed investigation of the distribution of the loads and stresses to which the shafts are subjected. On the portion of the shaft outboard from the pillow-blocks, there are a torsional moment and a bending moment due to the pressure upon the crank-pin, and another bending moment due to the action of the crank and after-part of the pitman. On the inboard portion there is a torsional moment, as before, a bending moment due to the reaction of the paddles and of the pillow-blocks, and a bending moment due to the weight of the wheel itself, plus whatever load it may carry in the form of ice. Variable shearing stresses are also distributed throughout the shaft. The Author calculates the several kinds of stress on twenty-three steamboat-shafts, the results of which are collected in a Table. The resultant stresses are, he argues, very much too high for satisfactory results; and in corroboration of this evidence there is the unanimous testimony that the appearance of the fractured shafts is crystalline, a recognized result of excessive strains. Ice, though not constantly present, is likely to give rise to abnormal strains. The entire area of the wheel-surface upon the "Port Eads," for instance, is 5,030 square feet; and a covering of ice, averaging 1 inch in thickness, would weigh 24,000 lbs., being an increase equivalent to 37 per cent. on the weight of the wheel and cranks. The deflection of the shaft at the middle is a serious matter. The changing of the sign of the stress for each half-revolution, and the peculiar racking strains induced by the deflected position of the shaft, seem to be mortal.

The remedy for both the excessive stresses and the deflection, without an inordinate increase in weight, is, according to the Author, to make the shaft hollow, and to lighten the wheel-structure by making it of iron as far as practicable. The hollow Krupp steel shaft placed on the "Harry Brown" was made by forging the shaft solid, and then boring out a central core. The facility thus afforded for examining the interior of the forging, and detecting internal flaws, is a decided advantage. The inherent defect and failure of solid steel shafts as made in the States is largely traceable to improper forging with light hammers, which, by extending the outer skin of the piece sets up high initial

stresses within it—compression externally and tension internally—so that a slight additional stress would rupture a piece, even though every specimen cut from it would show much resisting force. For instance, the shaft of the United States despatch boat "Dolphin," of American make, was broken on her trial trip, and test-pieces cut from the centre of the shaft and from the periphery, exhibited the following results for tensile resistance:—

	Breaking stress.	Elastic limit.	Elongation.
From centre	54,000 lbs.	34,000 lbs.	2 per cent.
From periphery . . .	80,000 "	32,000 "	18 " "

showing very variable quality, the central portions being little else than the metal as cast in the ingot, while the outer portion is of a highly-wrought texture.

The homogeneity of other steel shafts, notably those of Krupp's manufacture, and their freedom from initial stress, is proved by the fact of their running for some time after the cracks had started, without entirely breaking through. In the Krupp steel shaft of the "Harry Brown," the break, when discovered, was 9 inches long; and after three months' hard usage, the break had only extended 1½ inch, and was not more than 2 inches deep at any place.

D. K. C.

Mallet's Compound Locomotive.

By the late H. Tresca, Hon. M. Inst. C.E.

(Bulletin de la Société d'Encouragement, May 1885, p. 237.)

Already twenty-six compound locomotives have been either constructed or converted on Mr. Mallet's system—three on the Bayonne and Biarritz Railway, weighing 20 tons, constructed in 1876 at Creusot; two more for the same line, weighing 25 tons, exhibited in 1878; one on the Kiew-Balta Railway, converted to Mallet's system, and twenty others on the Orleans Railway, the Northern Railway of Spain, and several small lines in France, Austria, and Greece.

Mr. Webb, in England, and Mr. Von Borries, in Hanover, have applied the principle of compounding in other forms, the former on a considerable scale, the latter to 18 locomotives, both passenger and goods. But the credit of the first application of compounding to the cylinders of locomotives is due to Mr. Mallet.[1]

With respect to the economy effected by compounding on Mr. Mallet's system, comparative trials were made of original engines and the altered engine on the Kiew-Balta Railway. The altered engine had six wheels, of which the four-coupled wheels are 5 feet 7 inches

[1] Compound locomotives, on Nicholson's system, were tried on the Eastern Counties (now the Great Eastern) railway in 1850. See Institution of Mechanical Engineers. Proceedings, 1852, pp. 27 and 41.

in diameter, with 16½-inch cylinders, and 23½ inches of stroke; and it weighed 34 tons in working order. The alteration consisted in replacing one of the cylinders by another cylinder 23½ inches in diameter, and of the same stroke. The economy effected by compounding is estimated at 10 per cent. of steam for a given duty, and at 20 per cent. of fuel. On the Bayonne and Biarritz line, during the seven years 1878–84, there have been run 526,460 miles by from three to five engines, with trains averaging a gross weight of 52 tons, with a consumption of 14·11 lbs. of coal per mile run. One class of engines have cylinders of 9½ inches and 15¾ inches in diameter, with 47-inch driving wheels, and weighing 19½ tons in order; another class have 11-inch and 16½-inch cylinders, with 47-inch driving wheels, and weighing 24½ tons.

The Mallet engine, No. A7 on the South-West Railway of Russia, has 16½-inch and 23½-inch cylinders, with a stroke of 23½ inches, and 5 feet 7 inches driving wheels. The engine weighs 34 tons in working order.

D. K. C.

The Causes of Fracture and Breakage of Locomotive Crank-Pins. By K. Simchenko.

(Ingener, Moscow, April 1885, p. 165.)

The Author assumes the existence, among railway engineers generally, of a theory that locomotive crank-pins are fractured and broken by the violent strains set up by the piston compressing the accumulation of water from condensation, priming, &c., but remarks that it is almost always observed that the results of such compression is that either the cylinder cover, the piston, or connecting-rod is damaged or broken, the crank-pin remaining intact. Proceeding on this assumption, it is pointed out that if a careful examination of the crank-pin be made on the first appearance of the crack, it will be observed that this invariably occurs on the one side or semi-circumference of the crank-pin, viz., at the corner of the journal-shoulder or collar next the crank face.

With the crank at the bottom position the fracture is invariably discovered on the semi-circumference next to the cylinder. This uniformity of position of the initial stage of fracture has led the Author to the consideration of the causes to which this may be attributed, and to observe that such fracture occurs when the piston is at an intermediate position, say at half stroke, and not at the dead points, when compression takes place. With the piston at or near half stroke the crank-pin is subject to the maximum strains, that is, when the crank is in a vertical position, either at the top or bottom of its throw, where it is under the influences of three forces or strains, which he calls P, p, and S.

Force P = Pressure upon the piston transmitted through the piston-rod to the connecting-rod, the latter being assumed to be of infinite length, in order to

simplify the consideration of the influence which it exerts, relative to the pressure P, which is thus assumed to be the same for either top or bottom position of the crank, and to operate in a line parallel with the axis of the cylinder at a distance equal to the throw of the crank on either side.

Force p = Strain transmitted to the crank-pin by the momentum of the coupling-rods upon it, this operating in diametrically opposite directions to that of P in both positions of the crank; and lastly,

Force S = Strain transmitted to the driving crank-pin by impact, shocks, and vibrations due to the existence of flat surfaces worn upon the tire, which occur at a point perpendicular to the axis of the cylinder, when the crank revolves in an upward direction from the lower position.

It is thus shown that under the influence of such a combined momentum M, tending to shear or break off the pin, the fracture occurs, and this always on the same side.

If the measure of the moment M exceeds the limit of resistance of the sectional area of the crank-pin, the result is the appearance of a crack extending round that side of the pin subject to the bending or shearing moment M, which is always the same, both in the extreme upper and lower position of the crank; consequently the initial fracture of the pin must always occur upon the part or side referred to, and obviously at the section of least limit of resistance, that is, at the shoulder, near the crank.

These conclusions have been verified by careful examination of crank-pins, the fractures of which have been noted before being broken off; but if inspection be made of the appearance of even those which have been broken off, the same results will be attained, viz., the line of old fracture may be distinctly seen, showing a division between the old or initial fracture and the actual, more recent, breakage, which always occurs on one side of the centre line of the crank.

If the line of fracture occurs within an angle of 180° to the centre line of the crank, it may be attributed to the fact that the length of the connecting-rod is not of an infinite length, as was presupposed, and therefore the shocks and vibrations transmitted at the upper and lower positions of the crank are not identical. The Author considers it obvious that if the flat surface worn on the tire be of any considerable depth, $\frac{3}{8}$-inch to $\frac{9}{16}$-inch, although he has observed even more wear than this, then the force S becomes extremely great, and consequently the bending moment is seriously augmented, especially when such worn tires are frequently passing over points and crossings.

The Author concludes that once a fracture has occurred in the crank-pin of a driving-axle, however slight it may appear, it is impossible to arrest its extension, and, if not removed from service,

must inevitably break off sooner or later; but argues that fracture and breakage may be traced, for the most part, to the negligence which permits the continuance in service of badly-worn tires, and not to the strains on the piston, resulting from the compression of accumulated water of condensation and priming in the cylinder. The actual cause of fracture may be guarded against by avoiding the use of badly-worn tires, and the systematic inspection of the condition of the crank-pins. Should any trace of fracture be discovered, the crank-pin should be promptly rejected from service, which would obviate many accidents.

It is remarked that these conclusions only have reference to the fracture of driving crank-pins, and that as regards the fracture and breakage of coupled-wheel crank-pins, this must be attributed to other causes, viz., slipping, inaccurate adjustment of motion, coupling-rod centres, &c.

W. W.

A New Method of Lifting Water. By WERNER SIEMENS.

(Dingler's Polytechnische Journal, vol. cclvi., 1885, p. 284.)

In a sinking for brown coal in the neighbourhood of Berlin, a pit was put down to the seam through a depth of 30 metres of water-bearing sand, by Poetsch's method of freezing the ground, and sinking through the temporarily hard rock so obtained, but, owing to the great influx of water from the coal, the protecting coating of ice melted before the sides could be properly secured, and the pit was drowned by an influx of sand and water, which filled it up to the natural water-level of the country. At first it was attempted to relieve the pressure on the shaft by making numerous Abyssinian wells in the surrounding sand-waste, but these, owing to their small size, did not permit of the use of any very effective pumping power. It therefore occurred to the Author that a method imitating the action of gas-springs, geysers, and petroleum wells in nature, might be devised, by conveying compressed air to the bottom of the suction-pipe, and allowing it to escape through the mass of water, when, by its expansive action, a lifting power would be exerted, until an equilibrium with the natural pressure was obtained. The experiment was made with an Abyssinian tube-well that had been for some time in use, of 80 millimetres diameter, sunk to a depth of about 30 metres, with a suction-pipe of about 3 metres long. The tube was lengthened by 9 metres at the top, and a lead pipe of 20 millimetres, terminating in a copper wind-bore with numerous small holes, was put down to the bottom. This was connected with an air-compressor, formed by reversing the action of a portable steam-engine. As soon as the pressure in the air-vessel rose to three atmospheres, a current was established, the air escaping from the bottom suction-pipe passed into the water in the well-tube, and rose slowly in numerous small bubbles. As each bubble exerted a pressure on the water

surrounding it equivalent to that of the water it displaced, the equilibrium of the column in the two tubes was disturbed, and the water rose in the outer one, overflowing it if the latter was not too high. The velocity of the efflux which is constant so long as the air-current is kept up, depends upon the quantity of air supplied per unit of time, and the frictional resistance in the tube and suction-pipe. It must, however, be remarked, that the air-bubbles when rising quickly in the tube expand gradually to the atmospheric volume, displacing a correspondingly large volume of water, so that in calculating the lifting-power, the mean density of the air in the tube is to be used. If, therefore, the lift is to be equal to half the natural head measured from the bottom of suction-pipe, the specific gravity of the mixture of air and water in the tube must average about 0·66 in order to obtain hydrostatic equilibrium, and a volume of air equal to one-third of that of the water entering, if at a pressure of half the hydrostatic head, or of one-sixth, if at the pressure of the full head, must be expended. In actual working a further quantity must be expended to produce a proper velocity of efflux, and for overcoming the frictional resistance in the pipes.

The latter quantity represents the principal source of loss of work, but to this must be added that consequent upon the heating of the air by compression, and a third measured by the ratio of the difference between the velocity of the air when moving upward with the flowing water, and that of air rising through still water. If, however, the discharge takes place through a large number of fine apertures, so that the bubbles are small, and therefore only rise slowly in still water, and the speed of the water is considerable, the loss due to this cause is insignificant. In the experiments a discharge of 600 to 700 litres per minute was obtained, with a speed of 2·5 metres per second. In reality the velocity is much greater as the water, especially in the upper part of the tube, is mixed with a large quantity of air, and is thrown out in the form of a heavy scum at the top.

No calculations as to the economy of this method of lifting water have as yet been made, and many experiments would be necessary, not only for this purpose, but in order to arrive at the dimensions of pipes, proportion of height of lift to air-pressure, &c., in order to realise the best effect; but it may be taken to be applicable for many purposes, such as mining, irrigation, &c., where a well tube of any kind is available, and a communicating tube equal to at least half the height of the lift can be established below the level of the water-line. Gerlach[1] has pointed out that this system of lifting water was recommended by Löscher of Freiberg under the name of the Aërostatic pumping engine, in a pamphlet published in 1797, but it does not appear to have been tried except in laboratory experiments.

H. B.

[1] Zeitschrift des vereines deutscher Ingenieure, 1885, p. 311.

Draining-Machinery in the Valley of the Po.
By A. HÉRISSON.

(Bulletin de la Société d'Encouragement, May 1885, p. 266.)

The valley of the Po, the most extensively and most admirably irrigated district in the world, is not less remarkable for the importance and the excellence of the drainage works executed in recent years. In less than thirty years, from 1850 to 1879, upwards of 600,000 acres of marshy land in the provinces of Venetia and Emilia alone, have been drained and transformed into rich country. The long lines of chimneys bordering the Canal Bianco belonging to steam elevating-machinery, remind one of a Lancashire district. The question of drainage has from all time occupied the attention of the population of these Adriatic districts; but, in consequence of the difficulty and more often the impossibility of drainage by natural flow, it is only since the advent of steam that the work of drainage has been thoroughly performed.

Drainage by machinery in the valley of the Po is almost entirely carried out on one uniform plan. The ground to be drained is fenced round by catch-water trenches or canals. Occasionally, when necessary to prevent infiltration, the bottom of the canal is deeply trenched and filled with clay. Within the circumscribed territory a system of drains is cut, in which the water is conducted to the lowest level at a point conveniently selected, where the elevator is erected. By the elevator, the water is lifted into a canal or a river, in which it is carried off by gravitation. The elevators have to deal with variable volumes of water at variable heights; but, in general, the greater the height, the less the quantity to be lifted, so that the work to be done is in some sort constant. The heights vary generally in the ratio of 1 to 3.

Three systems of machines exclusively are employed as elevators: centrifugal pumps, turbines (*rouets*), and lifting-wheels (*roues élévatoires*). All of these machines are moved by steam-power, and they are the most economical. Piston-pumps employed to raise large quantities of water through small heights have shown not more than 35 per cent. of efficiency. Centrifugal pumps are of great variety of form, differing principally in the shape of the blades. The turbine is only a centrifugal pump on a vertical axis, of which the pipes are replaced by the sides of a well. It consists essentially of a circular crown-plate on a vertical shaft, on the under-side of which the blades of a centrifugal pump are fixed. In some instances, the blades, instead of being free at their lower parts, are fixed to a circular plate having a central opening equal to that left by the crown plate. The wheel is placed low enough to be submerged at all levels of the water. It is driven by toothed gearing or by bands. The difference between the turbine (*rouet*) and the centrifugal pump, is that the passages for water are much larger in the first than in the second. Consequently the velocity of the water is less and occasions less friction, whilst the

water escapes more freely. For small quantities of water, the pumps are more economical than the turbines, as the cost of construction of wells is saved. The turbines adapt themselves to great variation of level, whilst maintaining a high ratio of efficiency—about 75 per cent. Speed is, according to one system, altered by means of changes of toothed-wheel gearing to suit the various levels. According to another system, the speed is maintained constant for different levels, but the efficiency may fall as low as 60 per cent.

For this reason, in the Po valley, centrifugal pumps and turbines are being gradually replaced by lifting-wheels. These wheels are arranged like undershot water-wheels, but with the reverse action that the water is raised by the wheel. Originally, the blades or floats were straight and radial, and the wheels were of low efficiency—about 30 per cent. They dashed the water about as each blade entered it; whence their Italian name of *ruote a schiaffo* (literally, slapping wheels). The blades are now inclined at about 60° to the radius, and are formed with a double curvature, so that the water is lifted without agitation or useless elevation; and by means of a sliding iron shutter the opening for access of water to the wheel is formed at the lower part only. The efficiency is increased as the difference of levels is increased, and it averages 80 per cent. The wheels manufactured by Mr. Zangilorami are constructed entirely of iron, and some of them are made as much as 39 feet in diameter. The side walls are exactly dressed with a clearance off the wheels at most of one centimetre, or $\frac{4}{10}$ inch. The minimum immersion is 20 inches for a wheel of 26 feet. The circumferential velocity is constant—about 57 inches per second.

D. K. C.

The Deepest Bore-hole in the World. By — Mohs.

(Zeitschrift des Vereines deutscher Ingenieure, 9th May, 1885, p. 363.)

The deepest bore-hole in the world is at Schladebach, near Kötschau station, on the railway between Corbetha and Leipzig, and has been undertaken by the Prussian Government in search for coal. The apparatus used is a diamond drill, down the hollow shaft of which water is forced, rising again to the surface outside the shaft of the drill, and inside the tube in which the drill works. By this method cores of about 50 feet in length have been obtained. The average length bored in 24 hours is from 20 to 33 feet, but under favourable circumstances as much as 180 feet has been bored in that time.

Depths of various Bore-holes.

Name of Place.	Depth in Feet.
Domnitz, near Wettin	3,287
Probst-Jesar, Mecklenburg	3,957
Sperenberg, near Zossen	4,173
Unseburg „ Stassfurt	4,242
Lieth-Elmshorn, Holstein	4,390
Schladebach	4,515

The dimensions of the bore-hole at Schladebach are as follows:—

Total depth.	Depth.	Diameter.
Feet.	Feet.	Inches.
189·6	189·6	11·0
605·7	416·1	9·0
661·8	56·1	7·3
1906·5	1244·7	4·7
2259·8	353·3	3·6
3543·4	1283·6	2·8
4069·9	526·5	1·97
4514·6	444·7	1·88

The various strata passed through are as follows:—

	Feet.
Soil and sand, about	16
Clay	66
Sandstone (Bunter)	459
Anhydrite	59
Brine spring	..
Magnesian limestone (Zechstein)	144
Gypsum	36
Anhydrite	295
Marl-slate (Kupfershiefer)	3
Sandstone (Rothliegendes)	3,435

The borehole, which in January 1885 had reached a depth of 4,560 feet, was commenced in June 1880, but left after a year's work, recommenced at the end of 1882, and is still progressing. The cost up to January 1885 was about £5,000.

W. B. W.

Freezing employed for Shaft-sinking in Unstable Water-bearing Strata.[1] By J. Keller.

(Le Génie Civil, vol. vii., p. 99, 5 woodcuts.)

The principle and method of application of the Poetsch system of congelation, for shaft-sinking through running sand, have been previously described.[1] Since its first application in 1883, it was tried at the Max mine near Michalkowitz in Upper Silesia, but was abandoned before its completion, for reasons quite unconnected with its operation.[2] Two shafts, however, have been since sunk by this method with complete success, one shaft being at the Centrum mine at Königswersterhausen, and the other at the Emilia mine near the Dobrilugk station on the Berlin and Dresden Railway. Details obtained by the Author relative to the sinking of the latter shaft have enabled an estimate of the cost of the process to be arrived at.

At the Emilia mine, a round shaft, 8½ feet internal diameter, had

[1] Minutes of Proceedings Inst. C.E., vol. lxxv., p. 384.
[2] "Berg- und Hüttenmännische Zeitung," 18th April, 1884.

to be sunk into the lignite through a stratum of running sand 125 feet thick. An attempt to sink the shaft by the ordinary methods had to be abandoned after nine months' work, when 85 feet had been traversed. This shaft had deviated so much from the vertical that Mr. Poetsch began again at an adjacent site. Twelve tubes for conveying the freezing liquid were placed in a square trench 16½ feet across, and sunk 26 feet below the surface of the ground, the tubes being ranged along the circumference of a circle 13¾ feet in diameter. Twelve to fifteen days of continuous work were required for sinking a tube 100 feet. The sinkage of the shaft was begun fifty-three days after the freezing had been commenced, and was performed without difficulty at the rate of 1⅔ foot per day, with the aid of a very light timbering, The brick lining, 1 foot thick, was executed without any signs of pressure being exhibited. As soon as the shaft was completed, the tubes were easily drawn out after injecting a hot solution of calcium chloride, instead of cold, causing a thaw round the tube; and the tubes were taken out in excellent condition, perfectly fit to be used again. The work was commenced on the 1st of July, 1884, and completed about the 1st of March, 1885. Various details are given of the cost of the plant and wages, of which the following estimate is a summary:—

	£.
Allowance for interest and loss on plant, 25 per cent. on £3,000	750
Cost of carriage of plant	200
Erection and establishment	960
Use of the freezing machine for 240 days at £2 4*s*.	528
Sinkage (£1 17*s*. per lineal foot) and lining (£1 per lineal foot), 38 metres at say 250 francs, or 125 feet at £3 0*s*. 9*d*.	380
Superintendence, travelling expenses, &c.	382
Total	3,200

which is equivalent to £25 12*s*. per lineal foot. This shows that the system is economically practicable; and it offers decisive advantages under conditions presenting difficulties like those at the Emilia mine. It is evident also that its application might be extended to foundations and other works where unstable water-bearing strata have to be encountered.

L. V. H.

A New Method of determining Carbon in Iron.

(Stahl und Eisen, 1885, vol. v., p. 259.)

The following method has been for some time in use at Terre Noire. A weight of one gram of the sample, or less, according to the amount of carbon present, is digested in a tubulated retort with a solution of five grams of sulphate of copper in 30 or 40 cubic centimetres of water, at a gentle heat until the whole of the iron

is dissolved. The solution, when cleared from suspended matter, is drawn off by a siphon, care being taken that none of the solid residue is disturbed. About 30 or 35 cubic centimetres of pure concentrated sulphuric acid are then added, and, after cooling, four or five grams of pure crystallized chromic acid. The carbonic acid formed by the oxidizing action of the chromic acid on the separated carbon is determined by absorption, not as is commonly done in caustic potash, but in neutral carbonate of potash, which absorbs a second equivalent of carbonic acid producing bi-carbonate of the same base. The absorption-apparatus consists of a series of V tubes, each containing exactly one cubic centimetre of a standard solution, which, when saturated, represents 0·0005 of carbon. This solution is made by dissolving 4·65 grams of carbonate of potash in one litre of water. To indicate the point of saturation, manganate of potash is added to the solution (25 milligrams per 60 cubic centimetres) which is changed into permanganate by carbonic acid, and colours the solution red as soon as the whole of the alkaline carbonate is converted into bi-carbonate. As each tube corresponds to a constant weight of carbon, the total number of those discoloured by the operation will give the quantity of carbon to within 0·0005, or 0·05 per cent. without further calculation or weighing.

In conducting the operation the retort is at first heated until the contents are brought to a state of brisk ebullition, after which the heat is moderated or increased according to the rate of evolution of the gas. The current is maintained by an aspirator so regulated as to prevent absorption taking place in more than one tube at a time, dry air free from carbonic acid being introduced through the tubulure of the retort.

In order to determine the exact composition of the potash solution an experiment may be made from time to time with a compound of known carbon contents. Pure crystallized carbonate of soda is convenient for the purpose (0·0441 gram $Na_2\,CO_3$, containing 0·005 carbon). As regards accuracy the following tests (A) have been made in comparison with Boussingault's method (B).

	A.	B.
Steel	0·25	0·20
Martin steel	0·425	0·38
Watch spring	0·325	0·29
" "	0·525	0·50
Ingot iron	0·295	0·275
Cast-steel	0·62 0·615	0·63
Cast-iron	1·95	1·93

This method of determining carbon is considered to be preferable in many respects to those now in use. Only a single weighing is required, no time is lost in the tedious operation of filtering and washing precipitates, and no calculation is required. One chemist with a single assistant may complete fourteen determinations in a day.

H. B.

The Manufacture of Ferro-Manganese. By A. Pourcel.

(Le Génie Civil, vol. vii., 1885, p. 3.)

The name of ferro-manganese is given by the Author to any pig-metal containing more than 24 per cent. of manganese, which limit corresponds to an important physical difference, as the metal ceases to be attracted by the magnet when containing 25 per cent. or upwards of manganese. In England the limit is taken differently, the metal being called spiegel up to about 40 per cent.

The manufacture was commenced at Terrenoire in 1868, Prieger's method of fusion in crucibles being adopted. This process introduced at Bonn in 1866, consisted in fusing rich and pure manganese iron (pyrolusite) with about 20 per cent. of charcoal powder and 10 per cent. of spiegel (with 9–10 per cent. of manganese) in an air furnace, heated by coke. The capacity of the crucible was about $\frac{1}{4}$ cwt.; two were placed in the furnace at a time, and the fusion was effected in 9 or 10 hours, with a consumption of about 5 cwt. of coke. The yield of each operation was from 18 to 22 cwt. of metal, 80 per cent. of manganese, from 50 to 55 per cent. of the manganese contained in the charge being reduced. The cost of metal so produced was about £130 per ton.

Henderson's process, invented in 1863, was adopted in 1869. This is carried out in a Siemens furnace, similar to that adopted in the pig and ore open-hearth method of steel making; but with the difference that the bed and interior walls of the furnace are faced with carbon bricks. These are made of a pure class of gas-retort carbon, with only 1 to 2 per cwt. of ash, which is ground to the size of millet seeds, and made plastic by mixing it with about 10 per cent. of gas-tar completely freed from ammoniacal water by boiling. The mixture is moulded by hand in cast-iron moulds made in parts, and held together by clamps, in which they are fired. The firing takes place at a dark red-heat in a furnace, somewhat similar to the hollow fire used for annealing sheet iron; the tar escaping from the joints of the moulds, fires giving a considerable body of flame, which gradually diminishes and ceases entirely in about five or six hours. The bricks when removed are allowed to cool in the moulds, and if well burnt are as hard and easily workable as ordinary good fire-bricks. The extra cost involved by the use of the moulds in burning does not exceed four or five shillings per ton.

The charge, in the Henderson process, consisted of finely powdered manganese ore intimately mixed with quick lime, as free from silica as possible, washed bituminous coal slack, with not more than 3 to 5 per cent. of ash, and scrap iron or steel turnings; the whole being slightly moistened to make it coherent; the charging was effected by shovels with the damper closed to prevent oxidation. This was a very tedious and painful operation,

owing to the smoke and flame issuing from the working doors. From eight to ten hours were required to bring the furnace to a white heat, and from five to eight hours more for the complete fusion of the charge. In order to promote the final separation of the slag and metal a quantity of fluor spar, equal to about one-tenth of the weight of the lime used, was added a few moments before tapping. The yield, when working with good ore containing 46 to 52 per cent. of manganese, was from 5 to 6 cwts. of 80 per cent. pure manganese, from 45 to 50 per cent. of the metal in the ore being reduce. The cost of the metal so produced was under the most favourable circumstances about £56 per ton.

The great loss of manganese in this method is to be attributed to the imperfect contact of the different constituents of the charge, as although the carbonaceous matter was more than sufficient to reduce the manganese oxides, a large proportion was burnt to waste in the preliminary coking operation, and similarly the flux, though twice as much as the silica present, not only failed to decompose the silicate of manganese, but when the highest heat was obtained, and the atmosphere became oxydizing, manganite of calcium was formed, which floated on the top of the bath in imperfectly fused masses. Owing to these causes, and to the further addition of silica by the wear of the roof and flue bricks, the slag under the most favourable conditions contained twice as much manganese as silica.

The first highly manganiferous metal (30 per cent. pure manganese) made in the blast furnace was produced at the works of the Carniola Industrial Company, at Laibach, in 1873, from a mixture of spathic ore and oxide of manganese. In April 1875, the first trials were made at Terrenoire in a blast furnace, producing from 40 to 45 tons of Bessemer pig daily, and consuming per ton 19 cwt. of coke with 15 per cent. of ash. The hearth was faced with a layer of carbon and tar mixture, averaging about 10 inches in thickness, which was protected against burning while blowing-in by a coating of fire clay. The ore, containing iron 10·5 and manganese 33·5 per cent., was sufficiently calcareous to dispense with limestone flux, and in order to obtain fluidity in the slags, while maintaining an extremely basic character, other bases such as potash and baryta were introduced by the use of felspar and sulphate of baryta as fluxes. In this way, with a utilization of about one-half of the manganese in the ore, ferro-manganese of 50 per cent. was obtained, in forty-eight hours after the introduction of the first charge, which was frequently increased to 60 per cent. After eight days' working the furnace was put back on Bessemer pig. The average yield was below 11 and 12 tons in twenty-four hours, with the coke consumption of 34 to 38 cwts. per ton. The blast-pressure was about 5 inches of mercury, and its temperature 600° Centigrade. The gas of the furnace, when on 60 per cent. ferro-manganese, contained carbonic oxide, 5·50; carbonic acid, 30·00, and was practically incombustible, the stoves being heated by the gas of

an adjacent furnace on Bessemer iron; but when rich non-calcareous ores are used, and the weight of cinder does not exceed that of the metal, gas with 15 per cent. of carbonic oxide is obtained, which can be burnt under boilers; although from the amount of metallic substances carried over as dust or vapour, it is not suited for heating Cowper stoves. In subsequent trials, about 10 per cent. of bituminous coal was added to the coke charge to give gas sufficiently combustible for the boilers.

After the first experiments, a furnace with the hearth and bottom entirely constructed in carbon bricks up to the twyers was used. These are found to stand better than ordinary fire-bricks if the twyers are made to project from 8 to 10 inches beyond the walls. Such a hearth is easily cooled by water from the outside, as the thermal conductibility of carbon is about twelve times greater than that of fire-clay. By altering the charges and using richer manganese ores and a hotter blast (750° Centigrade), richer alloys were progressively obtained up to a maximum of 81 to 85 per cent. of manganese. A practical rule deduced from the numerous fluxing trials was to proportion the materials in the slag, so as to have twice as much lime as silica, and twice as much silica as baryta in the charge. The following are the details of the furnace work when on 82 per cent. metal, which was regularly produced for thirty-three days in succession:—

Charges.	Kilograms.	Iron.	Manganese.	
Huelva ore	480	14	252	
Almeria ore . . .	200	3	100	
Tafna ore	20	11	..	
	700	28	352 × 0·75 =	265 Mn
Limestone	220			28 Iron
Sulphate of Baryta .	60			23 C + Si
	980		Yield per charge .	315

The furnace was blown through two side twyers of 90 millimetres only, with a pressure of 120 millimetres, the temperature varying from 680° to 750° Centigrade. The furnace was driven at about half the speed required for Bessemer iron, the daily yield being about 10¾ tons, with a consumption of 54 cwts. of coke per ton. The amount of manganese reduced varied from 70 to 79 per cent. of the total contents of the ore, having remained at 77 per cent. for several days.

The slag corresponding to an 83 per cent. metal was of the following composition:—

Silica	27·75	Ferrous oxide . . .	trace
Lime	39·50	Manganous . . .	7·56
Magnesia	4·00	Sulphur	1·80
Baryta	3·90	Manganese . . .	5·80
Alumina	15·25		

Composition of two samples of ferro-manganese:—

Manganese	81·242	84·573
Iron	12·120	8·550
Carbon	6·600	6·650
Silicon	0·093	not del.
Phosphorus	not del.	0·234
	100·055	100·007

At Tamaris, where a better class of coke, with 10 per cent. of ash, is used, the consumption is less, being only 49 cwts. per ton of 82 per cent. metal. Although a considerable quantity of sulphur is introduced by the use of the sulphate of baryta as a flux, no portion of it is taken up by the metal, it being mostly eliminated as sulphides of calcium and manganese in the slag, and to a less extent as sulphurous acid in the furnace gases. When the zinciferous ores of Carthagena are used, considerable trouble is experienced from the deposits of cadmia on the flues at the furnace top, which requires to be cleaned out at intervals of about seven days. These consist essentially of oxide of zinc, an average analysis showing:—

Manganese . 3·34 Iron . . 1·56 Zinc . . 63·40 per cent.

The dust carried over by the gases is remarkable as containing a large amount of manganese, the metallic contents being:—

Manganese . 23·00 Iron . . 5·98 Zinc . . 1·36 per cent.

It is further remarkable as containing about 11 per cent. of baryta, mostly as an insoluble silicate, which seems to show that the sulphate of that base is entirely decomposed before reaching the twyers.

H. B.

Experimental Investigations of the Crucible-Steel Process.

By F. G. Müller.

(Stahl und Eisen, vol. v., 1885, p. 180.)

The analytical results recorded in this memoir, which is the first of a series upon the theory of crucible steel smelting, are the outcome of an investigation made at an Austrian steelworks in co-operation with the Author. The different charges were made in crucibles containing from 44 to 60 lbs., and melted in the ordinary way in a Siemens crucible furnace. The crucibles used were of three different kinds, the first A, with 48 per cent. of Styrian graphite (containing 75 per cent. carbon, and 13½ per cent. silica), and 52 per cent. clay; the second B, with 83 per cent. of the same graphite, and 17 of clay; and the third C, English black-lead

crucibles, with about 50 per cent. of carbon. These latter were very durable, and stood two or three meltings, while those of the second mixture were readily burnt through above the level of the charge, so that subsequently it was only used for the bottoms of the pots, the tops being made of the first mixture containing more clay. The experiments consisted in repeatedly melting charges of cast- and wrought-iron and crude forge steel without fluxes or additions, which were sampled and analysed after each cast. The results obtained up to the present time are as follows:—

A. *Crucibles of the A mixture.*

1. Styrian white cast-iron.

	Original. *a.*	First melting. *b.*	Second. *c.*	Third. *d.*
Carbon	3·593	3·709	3·773	3·636
Manganese . . .	2·038	1·910	1·856	1·864
Silicon	0·075	0·578	0·765	1·069

The successive meltings show the gradual transition towards grey cast-iron, which was completely effected by a fourth melting. The result of this was not, however, analysed.

2. Crude forge-steel.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·939	1·193	1·268
Manganese	0·240	..	0·224
Silicon	0·021	0·358	0·628
Phosphorus	0·012	..	..

3. Wrought iron.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·048	0·251	0·350
Manganese	0·083	..	..
Silicon	0·021	0·081	0·257
Phosphorus	0·041	..	..

The ingot from the first melting of the wrought-iron was full of bubbles, while that of the second was perfectly sound.

B. *Crucibles of the* 86 *per cent. Graphite mixtures.*

4. Crude forge-steel.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·915	1·130	{1·447, 1·454}
Manganese	0·214	..	0·192
Silicon	0·031	0·313	0·622

5. Wrought-iron.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·048	0·711	0·688
Manganese	0·114	..	0·091
Silicon	trace	0·290	0·624

The first cast was spongy, the second sound.

6. Forge-steel, melted in crucibles with tops of A mixture, which remained sound. One per cent. of pyrolusite was added each time.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·911	1·308	1·623
Manganese	{0·134 0·147}	{0·547 0·582}	0·738
Silicon	0·049	0·203	0·350

7. Wrought iron; crucibles similar to No. 6.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·040	0·671	1·336
Silicon	0·023	0·302	0·658

C. *English Black-lead crucibles; composition not determined.*

8. Crude forge-steel, in new crucibles.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	1·125	1·148	1·106
Manganese	0·179	..	0·141
Silicon	0·023	0·350	0·609

9. Wrought-iron, twice melted in an English crucible which had already been once used.

	Original. *a.*	First melting. *b.*	Second. *c.*
Carbon	0·090	0·324	0·390
Manganese	0·093	..	0·101
Silicon	0·019	0·202	0·393

Both casts were unsound.

Although the results obtained up to the present time are not sufficient for the foundation of a complete theory of the process, the following propositions may, in the Author's opinion, be considered as established. When crude steel is melted in graphite crucibles, whether of the richer or poorer kind, there is an increase of silicon of about 0·3 per cent. at each melting. Both hard and soft steel take up about 0·2 per cent. of carbon in crucibles of the A class. In those of the B class the increase is 0·45 per cent. at tool-steel heat, and 0·6 per cent. at scythe-steel heat.

The proportion of manganese is practically surcharged by remelting; when it is increased by reductions from pyrolusite added to the charge, there is a proportional diminution in silicon.

When the steel is subjected to the action of the furnace-gases carbon alone is attacked, silicon and manganese not being affected. The above propositions may be accepted as being the practical results of experiment, and independent of any theory.

The reduction of silicon is, in the Author's opinion, wholly effected by combined carbon in the metal, and not by the graphite in the crucible. This appears from the analysis 3 *b*. The reduc-

tion of 0·1 Si corresponds to a diminution of 0·086 C, according to the equation

$$2\,C + Si\,O_2 = Si + 2\,CO.$$

The energy of the reaction appears to be proportional to the combined carbon, white cast-iron taking up 0·5, and crude steel only 0·3 per cent. in the first melting.

The question of the origin of the silicon is not as yet satisfactorily settled, it may be derived from the quartz in the graphite, or from the decomposition of the clay substance in the crucible. The question of the reductibility of clay is still under investigation. The nearest approach to pure clay crucibles that the Author has obtained were those used at Bochum, with 38 to 40 per cent. of alumina, 48 to 50 per cent. silicon, and only 5 per cent. of coke, are almost without effect upon the metal; a steel with 0·7 per cent. carbon melted in one of them, showing only an increase in silicon of 0·04 per cent.

From the circumstance that sound castings are obtained from crucibles, even with soft iron, after the second fusion, the Author is of opinion that the special characteristic of the process (killing) is due to the gradual absorption of carbon and silicon. That gases cannot be driven out of steel by merely physical methods is, he considers, proved by an experiment, made by Mr. Wasum at Bochum, with soft iron from the basic process, taken from the ladle and kept melted for three hours in a crucible, which boiled in the ingot-mould just as much as when taken from the converter. The composition of the metal so treated was—

	a. Original from Converter.	*b.* After three hours in Crucible.
Carbon	0·015	0·020
Silicon	0·011	0·023
Phosphorus	0·023	0·034

As regards manganese, the whole of the experiments show it to be perfectly neutral. Even when present in large quantities, as in Series 1, it takes no part in the reduction of silicon. If it did, 0·4 of manganese should disappear for every 0·1 of silicon introduced, but in all cases it remains unchanged. That it has no effect in promoting the absorption of carbon and silicon is apparent from series 6. Indeed, these analyses show the contrary, the manganese oxide added being reduced at the expense of silicon, thus:—

$$3\,Mn\,O + Si = 2\,Mn\,O + Mn\,Si\,O_3.$$

The above reaction is *à priori* probable, from the well known affinity for manganous oxide. The fact that the furnace-gases within the crucibles burnt, though acted upon carbon instead of silicon, though unexpected, is in accordance with the Author's

observations in the German Bessemer process, namely, that at the high temperatures of the boiling period, the combustion of carbon completely prevents that of carbon and silicon. The temperature of the killing period in crucible melting is, however, decidedly higher than that of the converter during the period of boiling.

H. B.

On the Work developed in Rail- and Girder-Rolling.

By J. THIME, from the Russian by N. STRAUSS.

(Stahl und Eisen, vol. v., 1885, p. 246.)

The experiments recorded in this memoir, were made at Putilow's steel and wagon works in St. Petersburg, in November 1882, upon a reversing rail-mill driven directly by the steam-engine, without a fly-wheel. The works were then employed in rolling rails from ingots, produced partly in the converter and partly in the open-hearth furnace. These (1,000 to 1,055 millimetres long; 368 millimetres square at the thickest part, and weighing from 16¾ to 17 cwt. each), are taken hot from the moulds to the heating-furnace, and reduced to a square block of 181 millimetres, and from 3·1 to 3·12 times their original length, by fourteen passes through a blooming mill driven by a pair of engines having cylinders of 1,219 millimetres diameter, and stroke making sixty revolutions per minute, which is reduced by gearing to thirty revolutions of the rolls. No experiments were made upon this engine, as it is without indicator fittings. After a second re-heating, the final rolling is effected in a mill with a roughing pair of rolls with five grooves, and a finishing pair of six grooves, the section produced being a flat-bottomed one of 120 millimetres high, weighing 32½ kilograms per metre. Each ingot produced three full-length rails. The average production per twenty-four hours is one thousand and eighty rails; the maximum, on October 21st, 1882, was one thousand three hundred and eleven, weighing about 300 tons. The rail-mill engine, made by the Cockerill Company of Seraing, is called 1,800 HP. It has two horizontal cylinders of 1,150 millimetres piston-diameter, and 1830 millimetres stroke, the cranks being coupled directly to the neck of the bottom roll. The number of revolutions per minute varies from forty to fifty, the latter corresponding to an average piston speed of 3,050 millimetres per second; but as subsequently shown, the speed is often very much higher. The distribution is effected by plain slide valves, which only allow a small and invariable amount of expansion. The reversing is effected by an Allan link-motion, driven by an auxiliary engine whose slide-valve is moved by hand. There is a hydraulic cataract, but it is only used to deaden the shock upon the link motion in reversing, and the latter can only be fixed in full gear, whether forward or backward. The speed of the

engine is entirely regulated by throttling the admission, for which purpose a Sulzer double-beat valve of 400 millimetres is used, with a lift varying from $\frac{1}{4}$ to $1\frac{1}{2}$ inch, the steam-admission areas corresponding to these limits being $\frac{1}{150}$ and $\frac{1}{25}$ of the area of both pistons. The area of the steam-ports is $\frac{2}{23}$ that of the piston, while the corresponding ratio of the exhaust ports is $\frac{4}{33}$. The steam exhausts into the air directly, as although a condenser and an air-pump, driven by an independent engine, are provided, they have not been used, failing a sufficient supply of condensing-water. The total weight of the engine is about 196 tons. When working with steam at 75 lbs. (absolute) pressure, the tensile strain upon the cast-iron framing is about 36 kilograms per square centimetre, and upon the iron bolts uniting the different castings, about 180 kilograms per square centimetre. The rolls and housings weigh 130 tons 12 cwt. There are fifteen double-flued Cornish boilers, 9,150 millimetres × 2,185 millimetres, working at 60 to 65 lbs. pressure. Of these eight are required to work the rail-rolling mill, and burn 49 tons of coal per day, which corresponds to 4 cwt., or, in the most favourable case, to 3·4 cwts. per ton of rails rolled. The average loss of pressure on the main steam-pipe, 118 metres long, is about 5 lbs.

The experiments were made with a Richard indicator of the usual construction; a total number of one hundred and sixty diagrams being taken, sixty-four with No. 4 spring, varying from 15 to 60 lbs. pressure, and ninety-six with No. 3 (15 to 35 lbs.). The latter was preferred, as giving larger and more intelligible diagrams, as soon as it was determined that the steam-pressure in the cylinder while rolling rails did not exceed 35 lbs. The work expended in turning the unloaded engine, at different speeds from ten to one hundred revolutions per minute, with and without the rolls, was determined during the short interval that the mill was unoccupied at the change from the night- to the day-shift, but the diagrams obtained were very irregular, as owing to the low initial pressure (about 2 lbs. per square inch), and high piston-speed; the exhaust steam is partly compressed before it can escape, and the piston works in some respects like that of a blowing engine. With a boiler-pressure of 54 to 57 lbs., and a mean effective pressure of 2·86 lbs. in the cylinder, the work consumed by the engine and mill, making fifty revolutions per minute, or an effective speed of 5 feet per second at the circumference of the rolls, the HP. indicated was 156, of which 113·3 HP. were consumed by the engine, and 42·7 HP. by the rolls. The rate of elongation of the blooms in rolling was determined by measuring two of them after passing each groove of the mill. The original length of these, 3,048 millimetres and 3,352 millimetres, corresponded to the extreme variation in weight of the ingots rolled. The average figures obtained were—

Roughing rolls	0	1	2	3	4	5
Length	3,200	3,741	4,643	5,811	7,329	8,363 mm.
Extension	0	1·17	1·25	1·25	1·26	1·18

Finishing rolls . .	6	7	8	9	10	11
Length	9,880	10,896	13,658	15,990	21,362	23,065 mm.
Extension	1·14	1·10	1·25	1·17	1·34	1·08

Mean extension per passage 1·21.

The finished bar of 23,065 millimetres is cut into three rails of 7,215 millimetres, which leaves 1,419 millimetres for crop-ends. Shorter rails of 6,096 and 6,705 millimetres are cut from the lighter ingots.

The determination of the time required for each passage was made by three persons, of whom the first signalled the entry and exit of the bloom to the second, who observed the time with a stop-second chronograph, and called the result to the third, who noted down the result. The working speed was so great, that notwithstanding the utmost attention on the part of the recorder, many observations were lost; but a complete set was obtained for six different ingots, the mean of which gave, as the actual time of passing each groove :—

Roughing rolls. . .	1	2	3	4	5	
Seconds	4	5	4	5	5½	
Finishing rolls . . .	6	7	8	9	10	11
Seconds	6	6½	7	8	9	10

The corresponding speeds of engine and rolls were—

Roughing rolls . . .	1	2	3	4	5	
Speed of rolls . .	0·935	0·932	1·524	1·524	1·569 mm. per sec.	
„ engine .	30·7	30·6	50	50	51½ rev. per min.	
Finishing rolls . . .	6	7	8	9	10	11
Speed of rolls . .	1·646	1·676	1·951	1·999	2·367	2·297 mm. per sec.
„ engine .	54	55	64	65·6	78	75·7 rev. per min.

The piston-speed is almost exactly twice that of the circumference of the rolls. The time actually occupied in rolling, as computed from the observations, averaged 70 seconds, which, however, was more than doubled by the necessary operations of reversing, &c. The average interval between the entry of the first groove and the exit of the finished bar was about 150 seconds (2½ minutes). The maximum possible production at this rate would be 1,728 rails daily; but the highest production realized was 1,311, at which rate the mill was actually running, during eighteen hours of which $\frac{7}{15}$, or 8½ hours, represent productive work, and $\frac{8}{15}$, or 9½ hours running without doing work. For the average production of 1,050 rails daily, the mill is doing work for six hours, running empty for eight hours, and standing still for the remaining ten hours.

Indicator-diagrams were taken when the engine was at its maximum speed, that is, about the middle of each pass. From eight to twelve diagrams were taken for each groove, but with different rails. The results as computed are given in the following Table :—

—	No.	Pressure in cylinder. lbs. per sq. inch.	Indicated HP.	Useful work. I.HP.	Engines and Mill Resistances. HP.	Total Pressure on Grooves. Kilog.	Pressure in kilog. per square centimetre of Section of Grooves.
Roughing rolls.	1	11·50	413	306·57	95·78	24,600	95
	2	20·87	747	614·18	95·47	49,360	230
	3	17·50	1,024	816·80	156·00	36,900	(196)
	4	16·02	937	734·15	156·00	36,080	250
	5	12·91	778	579·00	160·00	27,700	(205)
Finishing rolls.	6	12·71	818	608·62	168·38	28,080	262½
	7	12·68	816	603·60	171·60	27,011	320
	8	10·00	749	511·87	199·68	19,680	191
	9	13·22	1,015	759·58	204·67	28,540	477½
	10	10·57	935	644·89	243·36	20,340	425
	11	7·38	654	385·12	236·18	12,500	300

The figures in brackets in the last column refer to grooves in which the metal did not fill the entire section. The area of the sections was computed from measurements of full-sized drawings, made with an Amsler planimeter, and also from the weight of the sections cut out in the paper. The differences between the two methods did not exceed 3 per cent. The former were considered to be the more accurate. The steam is cut off the engine at about three-fourths of the stroke, which at the normal speed of fifty revolutions, or 10 feet of piston travel per second, corresponds to 2,178 HP., assuming an absolute initial pressure of 75 lbs. without condensation, and 65 per cent. efficiency. The reputed 1,800 HP. therefore represents an efficiency of 54 per cent.

The much lower effect actually realized is due to the great loss of pressure by throttling, the absolute maximum pressure on the cylinder being only from one-half to one-third of that on the upper side of the steam-valve.

As a final result, the Author gives an estimate of the total work exhibited in shaping a rail from a block 181 millimetres square, by multiplying the effective work per second in HP. for each groove into the time of leaving and taking the sum of the clear products, as follows:—

Groove.	Effective work. HP. per second.	Time in seconds.	Total work for each groove in HP.
1	306	4	1,224
2	614	5	3,070
3	817	4	3,268
4	734	5	3,670
5	579	5½	3,184
6	608	6	3,648
7	603	6½	3,919
8	512	7	3,584
9	760	8	6,080
10	645	9	5,805
11	385	10	2,850
	Total for three rail lengths . .		40,302 HP.
	Or per single rail		13,434 HP.

The above total of 40,302 HP. is expended in extending an ingot 16·4 cwts. to 7·21 times its original length, an amount that contrasts very favourably with that required to do the same work hammering. This, as computed from Ramsbottom's data (110,000 HP. expended by a 30-ton hammer in drawing out an ingot of 2,460 kilograms to one and three-quarter times its original length), is 151,030 HP., or three and three-quarter times as much as that of the rolling-mill. The difference is due to the more rapid cooling of the metal under the hammer as compared with the rolls, and consequently its resistance to compression is greatly increased.

In a subsequent section a similar series of observations and computations are given concerning the production of ⊔ bars for wagon frames on the same work. The metal is of a milder character than that used for rails, and is rolled nearly at a white heat. The finished section, 235 × 88 millimetres, is produced from blooms 425 millimetres, shaped nearly to the section of the first groove, by eight passes through the mill, whereby it is elongated 6·45 times. The total work is 20,756·75 HP., whence it is computed that the work necessary to extend one kilogram of ingot iron to double its original length is approximately 15 HP.

H. B.

Quicksilver-Reduction at New Almaden. By S. B. Christy.

(Proceedings of the American Institute of Mining Engineers, February, 1885.)

The mercury produced by the mines of New Almaden in California during the thirty-four years ending 1883, has amounted to 79 per cent. of that of Almaden in Spain, and considerably exceeded the yield of all the rest of the world during the same period. The ore, which is almost entirely cinnabar, usually occurs associated with serpentine, dolomite, chalcedony, and chlorite, and only exceptionally in a sandstone. A fusible or liquid bitumen is also common. The rough stuff from the mine is subjected to a preliminary screening on a riddle of bars 1 to $1\frac{1}{4}$ inch apart. The smalls, or *tierras*, passing through are sent to the reduction works, while the lumps are picked over, those containing visible cinnabar being broken by hand to a maximum size of 9 inches, while the rest is rejected. The picked ore so obtained is known as *granza*. It forms about $\frac{1}{8}$ (9,600 tons) of the total yield (74,000 tons in 1883) of the mine, the tierras amount to about $\frac{4}{15}$ (20,300 tons), and the waste rock 45,000 tons.

In addition to the mine ore a certain quantity of tierras are obtained from the waste heaps of former workings, as well as some lumps somewhat smaller than the granza known as terreros. At the works a further class of large ore, known as granzita, is made, so that the final classification is:—

	Inches.	Per cent.	Tons.
Granza	9 to $3\frac{1}{2}$ rich	6 to 8	10,428·4
Terrero	6 „ $3\frac{1}{2}$ poor	1 „ 2	185·4
Granzita	$3\frac{1}{2}$ „ $1\frac{1}{2}$ „	1 „ 3	27,976·5
Tierras	$1\frac{1}{2}$ dust „	1 „ 3	
			38,581·3

The figures in the last column give the amount treated in 1883. The average yield of mercury was 2·875 per cent. Originally retorts were used for a short time, but they were soon replaced by furnaces of the intermittent type used at Idria and Almaden. These, in addition to other disadvantages, require the small ore to be made into *adobes*, or bricks, as a preliminary to treatment, which added considerably to the expense, and they have now been almost entirely replaced by continuous furnaces.

The first of those, the continuous coarse ore furnaces, based upon the Rumford lime-kiln, was introduced at Idria by Exeli in 1871, and was adopted in 1874 at New Almaden. Two of these furnaces are in use; they are called monitors, in allusion to their shape, and their iron casing. They resemble iron-ore kilns, having cylindrical stacks about 20 feet high, and 6 feet greatest diameter, with a conical bottom 4 feet across the base leading to the discharging aperture. The top of the stack is covered with a flat dome, having a cup and cone charging apparatus, which, for greater security, is protected by an additional cover, with a water or sand-joint. The furnace is heated by three lateral fire-grates, placed level with the top of the conical part of the kiln. The mercury vapours pass through three equidistant gas-flues at the top of the stack by a connecting pipe into a downcomer leading to the condenser. The ore-charge of 1,600 lbs. is mixed with about $1\frac{1}{2}$ per cent. of charcoal or coke to keep the column open. It is left in the hoppers to warm up before dropping it into the stack. The top of the column of materials is kept about 3 feet below the top of the stack. Pine or oak wood is burnt on the grates. As soon as the top of the column is of a dull-red heat, waste ore is drawn into the ashpits, and a new charge of equal volume is added. This is done at intervals of two hours. These furnaces work $9\frac{3}{4}$ tons in twenty-four hours, and as their capacity is about 21 tons, the ore is fifty-two and a half hours passing through. They are fired continuously, except when stopped by accidents. In 1882 they made 12,000 flasks (of 75 lbs.), at a cost per ton of ore of 7 per cent. yield, of 55 cents for fuel and 40 cents for wages.

The continuous fine ore furnaces, in which by far the larger part of the ore is treated, have been introduced by Messrs. Hüttner and Scott, to do away with the necessity of making up the *tierras* into bricks, which is a very costly operation. They are modifications of the Hasenclever-Helbig shelf-furnace, in which a series of inclined shelves, placed on opposite walls of a narrow vertical shaft, retard the descent of the column of fine ore. The first

experimental furnace had only two narrow chambers, with the shelves inclined at 45° to the wall, so that each shelf was perpendicular to that next below it on the opposite side. The distance between them was 3 inches, forming an aperture known as the shelf-slit. The fine ore when fed from a hopper runs from shelf to shelf until it reaches the bottom, and it comes to rest when the furnace is filled to the top, as an irregular zigzag column supported by the shelves. The end walls of the chamber are pierced with pigeon-holes, to allow the flame from the fire-place to pass under each shelf over the ore below, to a vapour-chamber on the opposite side leading to the condensers. At first, when the flame passed only once through the ore, it was discharged at too high a temperature, but this has been improved by placing arches across the firebox and vapour-chambers, so that the air and fumes have now to pass four times across the furnace on the way to the condenser. First, the air which enters the fire-place is drawn through the roasted ore, next the hot products of combustion pass through the newly-roasted ore, imparting a maximum finishing temperature, and finally they are passed twice through the colder ore in the upper half of the ore chamber. In this way the fumes leave the furnaces at a heat very little above the boiling point of mercury. In its latest form this furnace has two pairs of ore chambers 11½ feet long, 27½ feet high, and 25½ inches wide, with an 8-inch shelf-slit. The ore is charged from cups through hoppers at the top, closed by gas-tight slide-valves; the discharge is arranged by supporting the end of the ore-columns directly on the bottom of the draw-pit. It lies at its natural slope until raked out, and gradually feeds downward at a uniform speed. One ton of spent ore is drawn alternately from opposite sides of the furnace every forty minutes, the corresponding charge of one ton of *granzita* ore with 20 lbs. of coal being made immediately afterwards from the hoppers. As the furnace holds 45 tons of ore, which passes through at the rate of 36 tons per day, the charge remains thirty hours in the furnace. Firing is done with wood, 1½ to 1¾ cords being burnt per day for a produce of 15¼ flasks of mercury, corresponding to 1·664 per cent. on the ore treated. The cost for fuel is 35 cents, and for labour 29 cents per ton of ore. The total saving effected by these furnaces on the year's work of 28,688 tons is estimated at $41,800 over the old furnaces, and $30,756 on the monitors.

In 1883 29,000 flasks were produced from 38,581 tons of ore, or a yield of 2·875 per cent. This is the highest production since 1866; in 1865 67,194 flasks were obtained, but in 1874 the yield was down to 9,084 flasks.

The yield of the ore has declined gradually from 36·74 per cent. in 1850–51 to 2·875 in 1883. The richest mineral now obtained does not contain more than from 6 to 8 per cent.

H. B.

A Determination of the B.A. Unit in Terms of the Mechanical Equivalent of Heat. By LAWRENCE B. FLETCHER, Ph.D.

(American Journal of Science, 3rd series, vol. xxx., No. 175, July 1885, p. 22.)

If a coil of wire be immersed in a calorimeter filled with water, and simultaneous thermal and electrical measurements be made of the energy expended by the passage of a current of electricity through the wire, the value of either the unit of electrical resistance or of the mechanical equivalent of heat may be determined in terms of an assumed value of the other. By this method Joule in 1867, and Meyer in 1878, obtained values for the mechanical equivalent of heat, 1 per cent. and 0·5 per cent. respectively, greater than Joule's water-friction value. In both experiments the wire was assumed to be at the temperature of the surrounding water, and its resistance was calculated on this assumption. Now the wire was evidently hotter than the water, inasmuch as it was giving out heat to the water. To avoid this source of error, the research recorded in this Paper was undertaken by the Author at the suggestion and under the direction of Professor Rowland, of the John Hopkins University.

The amount of heat developed by a current c, flowing through a wire of resistance R, for a time t, is given by the equation $h = \frac{c^2 \mathrm{R}\, t}{\mathrm{J}}$, where J is the mechanical equivalent of heat. When a wire is enclosed in a calorimeter and joined up in circuit with a galvanometer, h, c and t can be measured. If R be measured in B.A. units, the experiment will give a relation between that unit and the mechanical equivalent. The Author finds R by joining its terminals with a large resistance R′, and measuring the current c' flowing through the latter. Then $c\,\mathrm{R} = c'\,\mathrm{R}'$, or $\mathrm{R} = \frac{c'}{c}\mathrm{R}'$; hence $\mathrm{J} = \frac{c\,c'\,\mathrm{R}'\,t}{h}$, which does not contain R, and therefore the effect of its temperature is eliminated.

The calorimeter was a cylindrical vessel of sheet copper filled with water and of 800 cubic centimetres capacity. In the vessel were three vertical glass rods around which the wire was coiled in a spiral. The wire was an alloy of platinum and iridium, and had a resistance of 1·8 ohm. It was varnished to prevent conduction to the water. Its ends were soldered to two stout copper wires, which were insulated by vulcanite tubes, and passing through the calorimeter and envelope, dipped into mercury cups. The water was stirred by a spiral blade of copper, supported on brass bearings, and kept in motion by a silk thread connected with a driving clock. The thermometer passed through the tubular part of the stirrer and was fixed in the centre of the calorimeter, surrounded by the stirrer and wire coil. The calorimeter was supported on vulcanite legs, within a copper vessel with

water-jacket surrounded by another hollow cover, which was also kept filled with water, and stood in a room of fairly constant temperature, so that the temperature of this envelope changed very little during the experiment.

In the main circuit the battery was joined up with a galvanometer, and the wires dipped into the mercury cups with the terminals of the calorimeter coil. The battery was made up of twenty-four one-gallon bichromates arranged four in series and six abreast, and gave a very steady current. The galvanometer was a single stout wire coiled once round a wooden circle 80 centimetres diameter. A sine galvanometer had its needle in the axis of this single coil, but slightly (at about 0·1 centimetre) out of its plane. The sine galvanometer was joined up to the calorimeter electrodes by a resistance coil of 30,000 ohms, forming a secondary circuit. Attached to this galvanometer needle there was a mirror, and by means of a telescope a short scale was seen on this by reflection. The direction of the current in each circuit could be reversed by means of commutators.

Taking the equation $J = \frac{c\,c'\,R'\,t}{h}$, there results c' the current in the sine galvanometer. The main current $c + c'$ flowing through the coil on the wooden circle was taken equal to c, since c' was so small in comparison as to be negligible. If G denote the constant of the fixed coil, G′ that of the sine galvanometer, H the horizontal magnetic force, θ and θ' the galvanometer deflections when the actions are in the same and opposite directions respectively; then

$$G\,c\cos\theta + G'\,c' = H\sin\theta$$
$$G\,c\cos\theta' - G'\,c = H\sin\theta'.$$

Hence $c = \frac{H}{G}\tan\frac{1}{2}(\theta + \theta')$, and $c' = \frac{H\sin\frac{1}{2}(\theta - \theta')}{G\cos\frac{1}{2}(\theta + \theta')}$.

Again, let l be the length of wire in the fixed coil, and b the eccentricity or distance of the needle from plane of coil, then

$$G = \frac{4\,\pi^2}{l\left(1 + \frac{6\,\pi\,b^2}{l^2}\right)}.$$

Hence the equation for J becomes—

$$J = \frac{R'\,l\left(1 + \frac{6\,\pi\,b^2}{l^2}\right)}{4\,\pi^2\,G'} \cdot \frac{H^2\,t}{h} \cdot \frac{\tan\frac{1}{2}(\theta + \theta')\sin\frac{1}{2}(\theta - \theta')}{\cos\frac{1}{2}(\theta + \theta')}.$$

The Author explains the various quantities in this expression: R′ is the resistance of the secondary circuit, *i.e.*, the sum of the resistance of the 30,000 ohm coil, the sine galvanometer and leads. To measure it a Jenkin bridge and high-resistance Thomson galvanometer were used, the standard of comparison being a 10-ohm

coil made by Warden, Muirhead and Clarke. Elliott's coils were used for small adjustments. It was found that $R' = 30012 \cdot 4$ at $19 \cdot 3°$ Centigrade. Its temperature varied from 19° to 24° during the experiment, and at the mean temperature of $22 \cdot 3°$ Centigrade, $R' = 30052$ which was used throughout. The length of wire in the fixed coil was $l = 264 \cdot 49$ centimetres. The eccentricity of the needle $b = 1 \cdot 2$ centimetre.

Professor Rowland found G' to be $1832 \cdot 24$ by measurement during the construction of the coil, and $1833 \cdot 67$ by comparison with another coil. The mean was taken as $1833 \cdot 19$. Hence the constant term was $10996 + 10^7$. Recent measurements make $G' = 1832 \cdot 53$, which is used in calculating the final result.

To measure H: The wooden circle with the fixed coil carried four smaller wires which could be joined up to the battery and an electro-dynamometer of the form given in Maxwell's treatise. These four wires with the needle formed a tangent-galvanometer. After careful determination of the constants depending on the dimensions &c. of the apparatus, the Author found that the horizontal magnetic force $H = 0 \cdot 11069 \dfrac{\sqrt{\sin \alpha}}{T \tan \phi}$, where α and ϕ are the mean deflections of the electro-dynamometer and galvanometer. Taking the mean of eight readings α was about 13°, and $\phi = 6°$, the mean value of T, the time of vibration of the small coil, was $2 \cdot 42$ seconds.

The Author next proceeds to describe the method of experiment. First H was determined. The calorimeter was weighed, filled with distilled water at 2° or 3° below that of the air, dried with a towel, again weighed and placed inside in the water-jacket envelope. The thermometer was then placed in position. The stirrer was started and kept in motion during the whole experiment. Readings were taken of the thermometers giving the temperatures of the calorimeter, water-jacket, air near steam of principal thermometer, the 30,000 ohm coil. The main circuit was next completed, galvanometer-readings were taken, the commutators being frequently reversed, also thermometer-readings taken. The time of each reading was carefully noted by a seconds clock. Alternate readings of galvanometer and thermometer were continued for about forty minutes, during which the temperature rose about 12° Centigrade. The circuit was then broken and the calorimeter allowed to cool by radiation for two or three hours, readings being taken as before. Another determination of H was made. Lastly the thermometer was taken out and the calorimeter weighed.

The average of each set of thermometer-readings gives the temperature of the thermometer for the mean time of that group. The difference between any two of these mean temperatures, corrected for radiation, and multiplied by the capacity for heat of the calorimeter and contents, gives the heat produced in the interval during which the differences of temperature of coil, water and thermometer are assumed constant; the coil is hotter than the water, and the thermometer cooler than it. The differences of temperature

depend on the rate of generation of the heat, and are approximately proportional to the square of the current.

The two very delicate thermometers used, known as Baudin 6,165 and Baudin 7,320, had been used by Professor Rowland in his determination of the mechanical equivalent, and were compared several times with the air thermometer and curves plotted, from which the Author gives tables.

To correct for radiation, the thermometer readings, taken when the calorimeter was cooling, were reduced to mean readings in mean times. Any two of these mean readings gave the radiation for that interval. Thus if t' and t'' are the temperatures at the beginning and end of an interval of T minutes, and τ is the mean temperature of jacket during that interval, then $t' - t'' = c\,\mathrm{T}\,\{\frac{1}{2}(t' + t'') - \tau\}$, where c is the coefficient of radiation. Sometimes stem and stirrer corrections were made. The mean values of c for different experiments vary considerably, being taken at $0^\circ{\cdot}0040$.

When all corrections are made, the differences between any two theoretical temperatures, multiplied by the heat capacity, gives the heat generated in that interval. Calculations are given of the total capacity for heat of the calorimeter, coil, glass, thermometer, &c., and the result is 30·4.

The galvanometer deflections θ and θ' were obtained graphically by plotting the readings of each group separately as functions of the time; then the theoretical mean readings were found for each interval by taking area of curve and dividing by the corresponding abscissa. Let a, b, c, and d denote these mean readings, then $2\theta = a - b$, and $2\,\theta' = c - d$.

The following are results, given by the Author, of one experiment in detail:—

SERIES of DECEMBER 9th.

	Grams.
Weight of calorimeter and water before experiment	1157·2
,, ,, after ,,	1157·0
Mean	1157·1
Weight of calorimeter	343·7
	813·4
Capacity of calorimeter	30·4
	843·8
Capacity reduced to weight in vacuo	844·8
Horizontal magnetic force before experiment	0·1960
,, ,, after ,,	0·1963
Mean	0·19615

Temperature of jacket	21°·5 to 22°·6
,, air near stem	22°·8 ,, 23°·4
,, 30,000 ohm coil	21°·5 ,, 22°·3
Thermometer in calorimeter	Baudin 7,320

Time.	Reading 7,320.	Stem.	Σ Δ.	Time.	Reading 7,320.	Stem.	Σ Δ.	2 θ°.	2 θ′.	J.
M. S.				M. S.						
8 40	19°·45	−0·010	0·000	25 14	25°·40	+0·009	+0·056	51° 8′·4	7° 35′·6	41,810,000
13 16	21°·15	−0·007	−0·018	31 9	27°·40	0·021	0·167	50° 57′·5	7° 28′·5	41,640,000
20 38	23°·80	0·000	+0·005	35 58	28°·98	0·029	0·299	50° 48′·5	7° 24′·4	41,640,000
25 14	25°·40	+0·009	0·056	42 54	31°·15	0·039	0·565	50° 40′·4	7° 21′·4	41,840,000

Time.	Galvanometer.	Time.	Galvanometer.	Time.	Galvanometer.	Time.	Galvanometer.
M. S.		M. S.		M. S.		M. S.	
7 50	237° 14′	15 40	237° 11′	28 5	237° 5′	39 0	237° 2′
7 0	259° 12′	17 5	258° 56′	29 15	258° 46′	41 0	258° 40′
10 20	229° 34′	22 0	229° 40′	32 45	229° 42′	44 15	229° 44′
11 30	207° 42′	23 25	207° 58′	34 0	208° 0′	45 25	208° 4′

GENERAL TABLE OF RESULTS.

Date	Nov. 24.	Dec. 9.	Dec. 14.	Dec. 20.	Dec. 22.	Jan. 26.	Feb. 16.
Thermometer . .	B. 7,320	7,320	6,165	6,165	6,165	6,165	6,165
Temperature of water	24°·3	25°·4	27°·0	26°·6	26°·3	27°·2	26°·2
Temperature of R′ .	23°·0	22°·1	23°·8	21°·7	23°·4	19°·1	20°·6
$\frac{J}{10,000}$ . .	4,240 4,248 4,229 4,274 4,216 4,204 4,225 4,224	4,181 4,164 4,164 4,184	4,180 4,222 4,217	4,207 4,195 4,206 4,204 4,182	4,198 4,216 4,232 4,218	4,194 4,192 4,205 4,193	4,207 4,219 4,174

The result of the experiment calculated with the new constant for the sine galvanometer is, J = 42,055,000 O, where O is the value of one-tenth of the 10-ohm coil in earth-quadrants per second.[1] The Author also calculates the result of the experiment from the formula $J = \frac{c^2 R t}{h}$, where R is the resistance of galvanometer-coil measured in the ordinary way, corrected to the mean temperature of water and further corrected for superheating. Thus J = 42,156,000 O. Discrepancies in this method are discussed by the Author, showing that this value of J is not so accurate as the preceding one.

The Author's standard coil was compared with a 10-ohm Elliott coil which agrees with the Cambridge standards at 20°·9 C.

[1] A resistance is of the same dimensions as a velocity, and the numerical value of *one ohm* is the same as the numerical value of a velocity of 10^9 centimetres (*one earth-quadrant*) per second.—W. R.

$$\frac{\text{W. M. \& Co.'s coil}}{\text{Elliott's coil at } 16 \cdot 3^\circ} = 1 \cdot 0017, \text{ whilst } \frac{\text{Elliott coil at } 20 \cdot 9^\circ}{\text{Elliott coil at } 16 \cdot 3^\circ} = 1 \cdot 0014.$$

Hence $O = \frac{1 \cdot 0017}{1 \cdot 0014} = 1 \cdot 0003$ B. A. units, and $J = 42{,}068{,}000 \times$ value of B.A. unit in earth-quadrants per second.

Rowland has discussed Joule's values, and deduces as the mean of the best results from friction of water, $J = 41{,}664{,}000$ at 26° the mean temperature of the Author's experiments.

Hence, one B.A. unit $= \frac{41{,}664{,}000}{42{,}068{,}000} = 0 \cdot 9904$ earth quadrant per second.

The experimental work of this research was completed in 1881, and the Author remarks that it cannot compare in weight with the elaborate determination of the ohm by direct methods, which have been made since that time in England and America.

W. R.

Electric Transmission of Energy. By — Boulvin.

(Bulletin de la Société Belge d'Electriciens, vol. ii., March 1885, p. 49.)

The Author first refers to the various methods of transmission of power from the great natural sources, where it is to be had cheaply, to the places where it can be used to greatest advantage. Compressed air has been employed in boring tunnels and working mines; high-pressure water, used under similar conditions; and wire-ropes, so largely used in Switzerland—all these require large installations, and the efficiency diminishes very rapidly as the distances become greater. Then the Author proceeds to what has been done by the new agent—electricity—giving the theoretical considerations and results, showing how far these have been borne out in practice.

The theory of the transmission of energy by electricity rests on:—

1st. Faraday's law.—The strength or intensity of a current is the same in every part of a conductor.

2nd. Ohm's law.—In a circuit of resistance R, with an electromotive force E, the intensity of a current $I = \frac{E}{R}$.

3rd. Joule's law.—The power W, or mechanical equivalent of the heat developed per second by a current of intensity I flowing through a resistance R, is given by the formula, $W = I^2 R$, or $W = E I$.

A current is induced in the wire coils of an armature when it is rotated in a magnetic field, like that formed by the field-magnets of a dynamo machine, the mechanical energy expended in producing rotation being converted into the energy of the electric

current, and conversely this current passed through another dynamo produces rotation in the opposite direction. Take two ideally perfect dynamo-electric machines, *i.e.*, machines which convert all the mechanical energy supplied to them into electric energy, and *vice versâ*. Connect the generator A to the motor B by a conductor, and put a galvanometer in the circuit. As the generator A is rotated faster the current produced increases, and after a time the opposing reaction of the magnetic field of B overcomes the friction and other resistances, and the armature of the electro-motor B rotates. For a given speed the generator drives the motor at a speed such that the power spent in overcoming the friction of bearings and Prony brake, together with the power spent by heating in the two machines and circuit, shall be equal to the power supplied to the generator. As more power is supplied the speed increases with the current and electromotive force, whilst in the motor B there is an opposing or counter-electromotive force, seeing B rotates in the opposite direction. Hence, in the installation, the galvanometer at first indicates an increasing current, but this soon diminishes, and when B has got up speed such as to produce the above equality of power, the current has returned to its initial strength. Thus for a given resistance in B, the current remains constant no matter how high the speed of A. If now the power absorbed by the Prony brake be diminished, the speed of A being kept constant, the counter-electromotive force of B will come up to that of A, the current will fall off, and consequently the power supplied to the generator need not be so great. Let E denote the electromotive force developed by the generator which produces a current intensity I in a circuit of resistance R, then by Joule's law, the power W furnished to generator = E I; and in virtue of the principle of the conservation of energy—

$$W = E\,I = I^2 R + w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $I^2 R$ is the heat developed in the circuit, and w is the mechanical or useful power given out by the motor. In the motor the electromotive force $= e$, and is opposing E, so that $w = e\,I$. By Ohm's law, the intensity I of current flowing through the circuit is $I = \frac{E - e}{R}$.

From equation (1)

$$w = E\,I - I^2 R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence the efficiency of transmission

$$\frac{w}{W} = \frac{E\,I - I^2 R}{E\,I} = 1 - \frac{I\,R}{E} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

By equation (2) the greatest value of w is obtained when $I = \frac{E}{2\,R}$, then the motor will run at such a speed as to reduce the current pro-

duced by the generator to half the value which it would have if the motor were at rest; hence for maximum rate of doing work the efficiency $\frac{w}{W} = \frac{1}{2}$, or 50 per cent. With more favourable conditions for working a higher efficiency than this can be obtained. The Author points out the analogous case in the steam-engine.

Keeping E and R constant, let e denote the counter-electromotive force, then—

$$W = E\,I = \frac{E\,(E - e)}{R}, \text{ and } w = e\,I = \frac{e\,(E - e)}{R}. \quad . \ (4)$$

R being constant, W and w are proportional respectively to

$$E\,(E - e), \text{ and } e\,(E - e).$$

The Author shows, by the well known graphic method, how to get the greatest amount of work out of the motor, under the given conditions. It might be possible to get a higher efficiency. Thus, suppose a waterfall developed 10 HP.; if it be wished to completely utilize this fall and establish an electric generator to take in all this power, the motor will only give out a certain part of it, say 25 per cent.; whereas if to the same generator 5 HP. only be supplied, a larger fraction of this power may be got from the motor. But after all this might be a bad plan, for the motor would furnish only a very small power.

Influence of resistance on efficiency.—Equation (3) shows that, other things being equal, as the resistance R increases the efficiency diminishes and the power wasted in heating the conductor increases. It is evident, that no matter how great the distance, R can be made as small as convenient by increasing the section of the conductor. The Author discusses the investigation of this method by Maurice Levy. The conclusion is that to have a high efficiency, it suffices to couple abreast a great number of machines and diminish the resistance of the conductor joining the set of generators to the set of motors. When a great amount of power is to be conveyed long distances the first cost of copper for the conductor becomes enormous, and the transmission of power in this way is out of the question. Better have a new type of machine specially fitted to fulfil the conditions.

The Author gives the calculation by Sir William Thomson for the economy of metal in electric conductors—the most economic size of conductor being determined by making the annual cost of power wasted in heating the conductor equal to the annual interest on the first cost of the copper, plus depreciation. The formula given does not apply generally; in fact it is remarked that, in some cases, for long distances, using conductors of section given by Thomson's formula, all the motive power would be wasted as heat.

Method by Marcel Deprez.—Comparing formulas (4), R being the total resistance of the circuit, the efficiency :—

$$U = \frac{w}{W} = \frac{e\,(E - e)}{E\,(E - e)} = \frac{e}{E},$$

whence

$$W = (I - U)\,\frac{E^2}{R};\ w = U\,(I - U)\,\frac{E^2}{R};\ \text{and}\ C = (I - U^2)\,\frac{E^2}{R}.$$

where C is the heat-waste in the whole length of the conductor. Hence for given values of W and w, U can be made independent of R, that is, the economic efficiency independent of the distance; to do so, for the different values of R, the term $\frac{E^2}{R}$ remains constant, that is, E varies as $\sqrt{R}$.

Deprez gives the following laws for dynamo-electric machines :—

1st. The electromotive force is proportional to the intensity of the magnetic field.

2nd. The electromotive force is proportional to the linear velocity with which the coils traverse this field, and consequently to the angular velocity of the rotating armature coils and to their distance from the centre, under the condition that the intensity of the magnetic field remains constant.

3rd. The electromotive force is also proportional to the length of the armature coils.

4th. The torque T, or turning moment (that is, the product of the resultant horizontal force × its distance from centre) for a given machine is proportional to the magnetic field and to the current intensity. It is independent of the speed of armature.

These first three are merely the general laws of induction; the fourth is the result of experiment. This is for the ideal perfect machine. The mechanical work supplied to the generator equals T N, where N is the number of revolutions per second; and the work given out by the motor equals T multiplied by n, the number of revolutions of the motor per second. Hence the economic efficiency equals the ratio of the speeds of the two machines.

By the experiment with two ideal perfect dynamos as above described, the current is constant and independent of the speed. But $I = \frac{E - e}{R}$, and R is constant for a given installation, so that $E - e$ remains constant. Now E and e being by the second law proportional to the speeds, it follows that the efficiency equals the ratio of two quantities having a constant difference; hence it is important to use as high speeds as possible.

The practical consequences of this are of the greatest importance. As the resistance R of the circuit increases, the current diminishes, and to maintain the same magnetic field, the number of coils must be increased, and with the same carcase of machine, much thinner wire must be used. The electromotive force E increases with $\sqrt{R}$. Now R being very great, it follows that the machines

ought to work at high electromotive forces, and for this high speeds are necessary. The drawback to this expedient—the employment of high electromotive forces—is the consequent difficulty of insulation and the danger to persons near the conductors.

In order to have high efficiency and to avoid heat-waste, &c., the only rational and practical solution is to employ large machines. On this point all are agreed. Marcel Deprez has proved, both theoretically and experimentally, that if all the dimensions of a machine, including diameter of wire in armature coils, be increased n times, the internal resistance will be $\frac{1}{n}$ that of the smaller machine, and the electromotive force for the same angular velocity, will be increased n^2 times. The increase in the diameter of the wires renders the construction easier. Hence big machines give the best results.

Experiment shows that the eddy currents, known as Foucault currents, generated in the mass of a soft iron armature, are negligible in the Gramme machine, in which the armature cores are made of insulated iron wire. With constant current in two identical machines the law for efficiency $\frac{w}{W} = \frac{n}{N}$, is found to be practically true, where N is the speed of the generator, and n that of the motor.

From a practical point of view, the Author next considers what portion of the power actually supplied to the generator can be usefully employed. In the conversion of mechanical into electric energy there is loss due to the slipping of belts on pulleys, friction of shafts on bearings, eddy currents, heating, sparks from collectors, &c., so that there is a coefficient, called "the coefficient of transformation" to be found experimentally for each generator as well as for each electro-motor. Besides, there is waste of energy along the conductor. Experiment has shown that this depends mainly on the current intensity, but slightly on the electromotive force. At the Munich experiment the loss through insulation of the line was 3 per cent.; at Grenoble it reached 6 per cent.

Let c and c' denote the coefficients of transformation for generator and motor, E and e the electromotive force and counter-electromotive force respectively, then the electrical efficiency $= \frac{e}{E}$, and the industrial mechanical efficiency $= \frac{e}{E} \cdot c \cdot c'$.

In the experiment at the Munich Exhibition in 1882, the generator was at Miesbach and the electro-motor in the Exhibition Palace, a distance of 57 kilometres (nearly 35½ miles) apart. The conductor was a double line of telegraph wire (iron) 4·5 millimetres diameter. The machines used were two similar Gramme-dynamos, series wound. The resistance of each was 470 ohms, that of the line 950 ohms, making the total resistance of circuit $(950 + 470) \times 2 = 1890$ ohms. The result was:—

Generator:—speed 1,611 revolutions per minute, $E=1{,}343$ volts, $I=0\cdot519$ amperes;
Motor:—speed 752 „ „ $e=850$ „

Theoretical efficiency $\frac{e}{E}=0\cdot63$.

The power received at Munich was $\frac{1}{2}$ HP., and the economical efficiency was about 25 per cent.

Trials on a larger scale were made at the Northern of France railway works in Paris (La Chapelle). The two machines were placed side by side, the circuit was formed of a double telegraph wire 4 millimetres diameter and 17 kilometres long. Complete dynamometric and electric measurements were made, and the results have been published in detail. The mean of the results is as follows:—

Of a motive power 10·395 HP. supplied to the generator, as measured by a transmission dynamometer, the motor gave out to the Prony brake 3·304 HP. Hence the industrial efficiency was 0·319. The resistance of the line was 160 ohms.

In one of the trials, for a generator speed of 910 revolutions per minute, the motor was making 726, and the industrial efficiency reached 43·3 per cent. The coefficient of transformation of the generator was 87 per cent., that of the motor 70 per cent.

Experiment at Vizille-Grenoble.—The machines were the same as at La Chapelle, but had been previously repaired.

Resistance of the line	167·0	ohms.
„ generator	56·7	„
„ motor	97·0	„
Total resistance	320·7	„

Mean of the results: Intensity of current was 2·64 amperes.

Generator—

Speed	1,040 revolutions per minute.
Electromotive force	2,787 volts.
Mechanical power taken in	9·69 HP.

Motor—

Electromotive force	1,940 volts.
Mechanical power given out	5·66 HP.
Electrical efficiency	69·5 per cent.
Industrial „	58·3 „

In one of the experiments, 6·97 HP. was transported with an electrical efficiency of 70·8 per cent., and mechanical efficiency of 62·3 per cent.

These brilliant results have confirmed the anticipations of Marcel Deprez, and have demonstrated the superiority of large machines over small ones.

W. R.

On the Regulation of the Speed of Electric Motors.

By Marcel Deprez.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1128–31.)

The Author claims that the method of "compound"-winding of dynamo-machines is first described by him in previous Papers,[1] and now considers what occurs in a machine of this kind when its functions are reversed, that is to say, when a current is passed into the ring and a constant difference of potential maintained at the terminals. In this case the currents traversing each of the windings (shunt and series) are in contrary directions, whilst they are of the same direction when the machine is used as a generator. The magnetisation of the inductors is then due to the difference of action of these currents instead of to their sum.

If the two terminals of the machine are put into communication with a source of electricity capable of maintaining constant their difference of potential, the machine will be traversed by two currents, the one traversing the ring and the winding to which it is connected, which winding is termed A, the other traversing the winding B. This latter current will be constant; the first, on the contrary, will have its maximum value when the ring is at rest. There is a velocity for the ring for which the electromotive force developed will exactly balance the difference of potential at the terminals; in this case the winding A becomes inactive and the magnetic field is solely due to the action of the current traversing the winding B. The motor effort is therefore nil. If the velocity of the ring be reduced, the product of the intensity of the field by that of the current traversing the ring is no longer equal to zero, as in the preceding case, and the intensity of the magnetic field diminishes, because the winding A acts in contrary direction to the winding B. A mechanical effort is exerted. It appears singular at first sight that the motor effort is increased by diminishing the intensity of the magnetic field.

Let ϵ be the difference of potential at the brushes of the ring turning in an independent magnetic field; E the electromotive force; R the resistance included between the terminals; I the quantity of the total current.

The machine as receiver, $I = \frac{\epsilon - E}{R}$. The motor work developed in unity of time is $E\,I$ or $\frac{E\,(\epsilon - E)}{R}$. If the velocity be supposed constant, the inverse electromotive force E is proportional to the intensity of the magnetic field, and the mechanical effort developed is itself proportional to the product $E\,(\epsilon - E)$. Now this product is nil for $E = \epsilon$ and for $E = 0$. It increases from zero to its maximum $\frac{\epsilon^2}{4}$, whilst ϵ decreases from ϵ to $\frac{\epsilon}{2}$.

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[1] "Comptes rendus," vol. xciii., p. 892 and p. 952.

The electromotive forces being proportional to the intensities of the magnetic field, it suffices to vary the latter from its maximum value (which corresponds to the case where the ring developes an electromotive force equal to ϵ) to half of this value in order that the electric motor may develope an effort increasing from zero to the maximum effort it can develope.

P. H.

On the Regulation of the Velocity of Electric Motors.

By Marcel Deprez.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1162–5.)

The considerations given in the preceding Paper admit of the determination of direction and amount of variations of intensity of the magnetic field of a receiving machine when the applied resistant couple varies, and the velocity of rotation and the terminal difference of potential are maintained constant. Let

ϵ be the difference of potential at terminals;
i the current traversing the first winding of the inductors;
i' the current traversing the second winding and the ring;
n the number of turns of the first winding;
n' the number of turns of the second winding;
r the resistance of the first winding;
r' the sum of the resistances of the second winding and of the ring;
E the contrary electromotive force developed by rotation of the ring;
v the velocity of the ring in revolutions per second.

The current $i = \frac{\epsilon}{r}$; the current $i' = \frac{\epsilon - E}{r'}$; E is proportional to v and to the intensity of the magnetic field. But this intensity produced by a helix of n turns, traversed by a current i, is a function of the product $n\,i$; if a second helix of n' turns, traversed by a current i', acts at the same time as the first on the iron core of the inductor, occupying the same relative position with regard to the core, the intensity of the field will be a function of $n\,i \pm n'\,i'$. This may be written—

$$n'\left(\frac{n}{n'}\,i - i'\right),$$

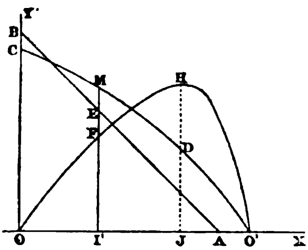
or, replacing i by its value and putting $\frac{n\,\epsilon}{n'\,r} = i_o$,

$$n'\,(i_o - i').$$

The magnetic field is then the same as would be produced by a helix of n' turns traversed by a current $i_o - i'$.

Take two rectangular axes O X, O Y. On X lay down the current i', and on Y the electromotive force e developed by the ring when $v = 1$. Take O O$' = i_o$ and starting from O$'$ carry to the left the values of $i_o - i'$ by increasing i' from zero to i_o; the curve O$'$ D M C is a characteristic the concavity of which is turned towards x negative instead of towards x positive, as is usual.

Let it be proposed to find the velocity that the machine will take when its terminals are put in communication with a source of electricity of constant potential-difference, with a given resistant couple applied to the ring. The mechanical work expressed in watts developed by the ring in the unit of time is equal to E i', or, as E $= v\,e$, $v\,e\,i'$; the work per turn is then $e\,i'$, that is, the product of O I$'$ by I$'$ M of the characteristic. Let there be constructed a new curve O F H O$'$, called the curve of moments, having for abscissæ the different values of i', and for ordinates the lengths proportional to O I$'$ $\times$ I$'$ M or $e\,i'$. It is easy to see that this curve cuts the axis of x at the origin and in O$'$. When the characteristic O$'$ D M C is a right line, the curve of moments is a parabola of which the vertex H has for abscissa $\frac{\text{O O}'}{2}$.



From $i' = \frac{\epsilon - E}{r'}$, $E = \epsilon - r'\,i'$. Putting down the values of E on y and those of i' on x, the right line A B is obtained, which cuts the axis of x at a distance from O equal to $\frac{\epsilon}{r'}$, and the axis of y at that point B which has for ordinate $E = \epsilon$.

The characteristic O$'$ D M C, the curve of moments O F H O$'$ and the line A B admit of determining the velocity taken by the machine. The resistant couple being represented by F I$'$, the current O I$'$ is immediately given by the curve of moments. Now, to this current corresponds an electromotive force, I$'$ E, which is given by the equation $E = \epsilon - r\,i'$, of which the line A B is the geometrical representation. But, on the other part, this same electromotive force deduced from the characteristic will have for its value I$'$ M $= \epsilon$.

The relation $E = v\,e$ gives $v = \frac{E}{e}$. The velocity sought is then given by the ratio of I$'$ E to I$'$ M. To make the velocity constant needs the power to render this ratio constant. This is strictly possible only when the characteristic is a line, and that the line A B passes through O$'$, which leads to the equation of condition $\frac{\epsilon}{r'} = \frac{n\,\epsilon}{n'\,r'}$, whence $n\,r' = n'\,r$. If this condition were fulfilled, a curious consequence would result, that the machine once brought

to rest, would not again start, because the magnetic field would always be nil, whatever the current. If, instead of seeking to render the velocity of the machine strictly constant, which is impossible, superior and inferior limits are given, the same construction admits of easy resolution of the question.

Finally, if the working velocity be supposed established, and the resistant couple very small, we may increase it from zero to J H; the current will increase from zero to O J, and the working of the machine will be stable, but if J H be exceeded, the equilibrium becomes instable and the machine completely stops.

This method permits besides the resolution of numerous other questions.

P. H.

The Electric Lighting of Antwerp. By L. Nothomb.

(Bulletin de la Société Belge d'Electriciens, vol. ii., February 1885, pp. 25–43.)

Authority has been granted to the *Compagnie Générale d'Electricité* to light the east end of Antwerp. The excessive price of ground in the district to be lighted obliged the company to select a place at some distance from it for their works or central station, which is intended to light the public roads, dwelling-houses, theatres, cafés, and private hotels, as well as to supply motive-power to some industrial establishments. More than 10,000 glow-lamps, and several hundred arc-lamps will be necessary to light that part of the town. Already the installation consists of 3,000 glow-lamps of 16 candles each, and 100 Gülcher arc-lamps. Electric light will be actually supplied to the inhabitants of the town at the same price as gas, and in each house will be placed a Ferranti meter indicating the consumption of current. The Author gives a plan of the district and arrangements, with drawings of the apparatus and plant.

Steam-engines.—There are two compound twin-cylinder non-condensing engines, controlled by patent steam-regulator, and made to special design at the Seraing works. Each machine is 400 indicated HP., has speed eighty-five revolutions per minute, and the maximum effective pressure in the boiler is 6 atmospheres. The diameter of the large cylinder is 0·860 metre, and of the small cylinder, 0·520 metre. The piston-stroke is 0·110 metre. The fly-wheel is 4·80 metres in diameter, and the rim 1·10 metre broad, to receive a double leather belt one metre broad. Special attention has been given to the lubrication.

There are four De Naeyer boilers of 150 HP. each. The makers guarantee a poundage or evaporation of eight or nine times the weight of fuel burned. Three of these engines are always working, whilst the fourth is being cleaned.

The dynamo machines are driven from a counter-shaft 0·16 metre in diameter, running at a speed of about 150 revolutions per

minute. The driving-pulleys, 2·70 metres in diameter, are of wrought iron, and fitted with gearing so as to run loose when desired. The central station is 400 metres from the district to be lighted. The Gülcher dynamo is wound with a view to keep the difference of potentials constant, not only at the terminals of the machine, but also at every point in the main and branch conductors. The constant electromotive force at the extremity of the principal conductor is 70 volts, and a loss of 4 volts is allowed in the branch conductors. The size of conductor is determined by Sir William Thomson's rule, that the cost of the energy wasted in heating the conductor should be equal to the interest plus depreciation on value of the copper employed. The principal conductor is 410 metres long, or for going and return 820 metres. It is made up of five positive and five negative cables. Each cable consists of nineteen wires, of 4·88 millimetres diameter, twisted together; so that the section of each cable is 355 square millimetres, and the total section of each group of cables, 1,775 square millimetres. The total strength of current is 1,500 amperes, with a total loss of 12·3 volts, equivalent to 28·73 HP. Total resistance at 15° Centigrade is 0·0082 ohms. A Table is given showing the lengths, sections, and resistance of the various leads, with the current each is to carry. Then follow details of the distribution. The insulating material consists of a bituminous mixture. The cables are placed in cast-iron boxes containing pure bitumen, with pieces of wood, called bridges, at short distances apart, to keep the cables well separated. The box is provided with an iron plate for cover. This is the Callender system used at Victoria Station in London, &c.

Opposite each house, on the line of the main cable, is placed a distributing box, made of cast iron, and having branches radiating from the centre, cast with the rest of the box. In this are fixed the house-leads, which terminate in the cellars. There, on one of the conductors, is a double fusible bridge, or cut-out, and on the other a general switch. A single dwelling can thus be simply switched out at any time without fear of dangerous contacts. In an establishment the arc- and glow-lamps are on separate circuits, and a meter gives the quantity of current consumed in each circuit separately.

Among the more important installations may be mentioned those at the Théâtre de l'Eldorado, Palais Rubens, and Scala. The Author gives plates showing the plan adopted at the Théatre de l'Eldorado.

The Gülcher dynamo electric machine is compound wound, and constructed to produce the greatest possible quantity of electricity with feeble electromotive force. The Author gives detailed drawings with description. Four brushes are used, and the winding is such that any two of these suffice to collect the current, so that a pair of brushes can be changed, when the machine is running, without at all affecting the current. Mechanically the whole machine is built up of a series of pieces, each independent of one another, and replaceable at a moment's notice by duplicates kept

in stock. The low constant speed of this type of dynamo permits the use of large pulleys with broad belts. From an economical point of view the efficiency is very high. The difference of potential at terminals is constant, and the characteristic curve is sensibly a horizontal straight line.

The Gülcher arc lamp is noted for its great simplicity; having no wheel-work, it may be employed even in places where dust cannot be avoided. Detailed drawings, with explanation of the connections and working of the lamp, are given. One carbon lasts eight hours, and an arrangement for two carbons gives the average time of lighting seventeen hours consecutively, which is ample for practical purposes.

The glow-lamps are supplied by Messrs. Siemens Brothers, and the 20-candle Lane-Fox lamp gives 240 candles per electrical horse-power.

Each dwelling is to be provided with a Ferranti current-meter. The action of this apparatus depends on the rotation produced by amperian circular currents. A sectional elevation and plan of this meter are given. The current passes from the conductor into a metal plug fixed in a solid piece which is screwed into a mass of iron. Inside this there is a central chamber filled with mercury, insulated by a guard-ring of ebonite, so that the current only enters the mercury by the centre. A thin plate of copper, completely immersed in this mercury, carries a vertical axis or spindle, which communicates a movement of rotation to a system of wheels indicating the number of revolutions. The current leaves the mercury by a circular band of copper, carefully insulated, and flows away along the conductor. The constant current causes the mass of mercury to move at a uniform rate, carrying the copper plate round with it. This current is generated and increased by the mass of iron, which becomes an electro-magnet, and thus concentrates and intensifies the magnetic field. Any acceleration in the motion of the mercury is to be carefully avoided. The number of revolutions is proportional to the strength of current passing through the apparatus. The different types of Ferranti meters employed at Antwerp measure from 1 to 500 amperes, and give perfectly correct readings.

A plan of the main switchboard, consisting of an arrangement of switches with fusible bridges or cut-outs, is shown, connecting the dynamos with the principal circuit, and enabling any one dynamo to be instantly replaced by another, kept always ready in reserve. Each dynamo has its own switch and cut-out, with shunt circuit for volt-meter, whilst in the dynamo room a main switch controls the whole current in the main leads.

W. R.

Zinc-Manganese Battery. By Dr. EMIL BOETTCHER.

(Centralblatt für Elektrotechnik, vol. vii., 1884, pp. 51–53.)

In some experiments with Leclanché batteries, the Author used for the negative element plates consisting of 40 per cent. of retort-carbon, 55 per cent. of manganese, and 5 per cent. of binding-medium, the whole being combined under a hydraulic pressure of 200 atmospheres. The dimensions of the plates were 12 centimetres long, 4·2 centimetres wide, and 2 centimetres thick. The electromotive force of a cell composed of such a plate, and an amalgamated zinc rod in a solution of sal ammoniac was 1·56 volts. From a calculation of the quantity of heat generated and absorbed by chemical action in a battery of this kind, the Author concluded that sulphuric acid would give a better result than the solution of ammonic chloride, provided a counter electromotive force was not set up in consequence of the formation of manganous sulphate and liberation of oxygen; but no such opposing force was manifested, although manganous oxide was dissolved. The electromotive force was 2·2 volts, or almost 50 per cent. higher than that of a Leclanché battery, in which a solution of sal ammoniac forms the exciting liquid. After remaining on short circuit for six hours, the cell gave 2·1 volts, and at the end of seventy-six hours, the electromotive force was rather more than 1 volt.

J. J. W.

Electric Accumulators. By P. NÉZERAUX.

(La Lumière Électrique, vol. xvi., 1885, pp. 375–78.)

This is an article professedly descriptive of the superiority of the Author's system, which employs amalgams, over that of Faure's which employs oxides. For an accumulator of perfect practical conditions it is requisite that (1) the matter employed in the composition of the couples should itself have very great cohesion, without which the apparatus will not long resist the action of the primary current; (2) that this matter should be in a state of perfect capillarity, in default of which the chemical action is irregular and too slow; (3) that the electric conductivity be such as is compatible with rapid formation; (4) that the commercial capacity shall be about 14,000 kilogrammetres per kilogram of useful matter, principally for the purposes of locomotion; (5) that the current have both in charge and discharge a quantity of ½ to 3 amperes per kilogram without deterioration of the spongy matter; (6) that the positive polar plates suffer little or no destructive action from the primary current; (7) that the apparatus present a large margin in electro-chemical work, so that too prolonged action of the primary current from carelessness of work-

people may not pass the limit of cohesion; (8) that the agglomerated matter have a very spongy structure, because upon this electric capacity depends. The Planté cell has perhaps best fulfilled these conditions. But its commercial application is impracticable on account of the length of time necessary to obtain spongy layers of sufficient depth. All systems based on the use of sheets or leaves of lead, of agglomerated wires of lead or of lead powder are imitations of the Planté system with the disadvantages that they lose in cohesion. Mixed systems using oxide of lead and shot are characterised as unscrupulous infringements of Faure's system. Other systems using zinc, copper, iron, sodium, potassium, &c., have given only mediocre results. The Author reviews the well-known process of construction and formation of the oxide battery, in which a paste of minium, moistened with dilute acid, is packed into the small squares of a cast-lead plate. He points out that excessive care is necessary to obtain in this manner plates of uniform filling; and that such plates when filled and dried are better charged placed at a distance of 10 millimetres from each other, and using a solution of 5 per cent. acidulated water, than with a distance of 5 millimetres and a 10 per cent. solution. Also that plates of 6 millimetres thickness restitute no more in discharge than those of 3 to 4 millimetres. The commercial capacity of such a cell is 5 to 6 ampere-hours per kilogram of plates, but this may be increased to 10 to 11 ampere-hours per kilogram, with, however, insecurity of work as regards the positive plates. The Author calculates that the usages of the positive plates by peroxidation is about $\frac{1}{28}$ millimetre for each charge with plates of 4 millimetres thickness. The negative plate has not the texture nor malleability of spongy lead as in Planté's plates, but may be crumbled between the fingers. The efficiency of quantity is 85 to 90 per cent. of the electricity furnished during the charge; the efficiency of electrical work 63 per cent., and the efficiency of electrical work available at the terminals of the apparatus 47 per cent. of the motor work.

The plates on the Nézeraux system are filled with an amalgam of equal weights of lead and mercury, the mercury thus forming $\frac{1}{3}$ of the weight of the filled plate; and are filled with this amalgam pulverised and pressed. These plates being then charged, the mercury of the positive plate is driven out, and is found at the bottom of the charging vessel. The peroxide obtained with amalgams is much more solid, more spongy, and less friable than that provided by the oxides, and the capacity of the plates may be increased by giving greater thickness. The commercial capacity of such a plate containing 70 per cent. of spongy lead attains 18,000 to 20,000 kilogrammetres per kilogram of plates. In the Nézeraux system 100 kilograms of plates can contain 75 per cent. of spongy lead, whilst in the Faure system only 33 per cent. has been attained. The electromotive force is 0·1 to 0·2 volt higher. 80 per cent. of the work accumulated is returned instead of 63 per cent. The presence of mercury in small quantities in the

negative plates increases the activity of the couples, prevents polarization, and impedes local action due to impurities of the lead.

P. H.

On the Variation in Volume of Lead in Electrical Accumulators.

By Emile Regnier.

(L'Électricien, vol. ix., 1885, pp. 261–277.)

Initially the plates of accumulators of the Planté type consist of solid metallic lead; during the process of formation or charging, the positive plate becomes superficially transformed into peroxide of lead, the weight being thus increased while the density is diminished; the negative plate remains practically of the same weight, but is rendered porous, and consequently is of less density than before; the process of charging results therefore in an expansion of both plates.

After discharge sulphate of lead is formed on both plates, the weight being further increased but the density diminished, and less than that of spongy lead, so that there is a further augmentation of volume; now on recharging, the weights, mean densities, and volumes will be the same as before the discharge, and not that of the initial solid lead. The plates will therefore increase in volume during discharge, and diminish during charge.

From the given weights and densities of the different chemical products, the effect of the forming process of the Planté plates is to produce a linear expansion of 1·5 to 2·5 per cent., according to the depth of penetration.

As regards the Faure plates, theoretically the change of volume in formation is nil, but from the fact of the minimum being soaked in sulphuric acid, there would probably be a slight diminution of volume.

With the plates formed by either process the mean linear expansion during discharge will be from 4 to 7 per cent., according as the penetration is one-eighth or one-quarter of the thickness of the plate; but this expansion would not be equal in all directions, but would act most in the direction of least resistance. In recharging the plates would tend to return to their original form, but the want of elasticity in the leaden backing would result in detaching the superficial active deposit.

In the case of Faure plates, where the material is packed in leaden gratings, during the first discharge the expansion affects the plate as a whole, but in the subsequent charge the pulverulent material is alone acted on, and reduced in volume, and thus the cells become too large for their contents, and the resistance is considerably augmented.

There is no doubt that to this mechanical effect can be ascribed the fact that only a fraction of the substances introduced can be

practically employed; as the process of charging reduces the contact pressure between the lead conductor and the badly conducting material which it encloses, while during discharge the liquid is squeezed out of the pores of the spongy material, and it is therefore left dry and inactive.

The improvement of accumulators in the way of greater electrical capacity and longer life, can accordingly be effected by using finely divided materials, employing them in small thickness, and making the conducting supports of large surface, and at the same time sufficiently supple to follow the movements required by the processes of charging and discharging.

The Author states that his form of plate, a long thin band deeply corrugated and folded thrice transversely, fulfils these requirements, though it was not arrived at as the result of the theoretical deductions above given; but on the contrary, from watching the behaviour of these plates, he was led to the investigation of the cause which could produce the variations in volume which he had noticed.

F. J.

Determination and Registration of the Charge of Accumulators.

By Messrs. A. Crova and P. Garbe.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1340–1343.)

Admitting that the chemical reactions produced on the two plates of an accumulator are, during charging, the transformation of the layer of sulphate of lead on the positive plate into binoxide of lead, and that on the negative plate into metallic lead, the charge corresponding to the decomposition of 1 equivalent of sulphate of lead on each plate will transform:—

1. At the positive pole, PbO, SO^3 into PbO^2, liberating 1 equivalent of $SO^3 HO$.
2. At the negative pole, PbO, SO^3 into Pb, liberating 1 equivalent of $SO^3 HO$.

The electro-chemical equivalent of lead being 1·0867 milligram, and that of the acid 0·51445 milligram, each coulomb stored will act on 1·0867 milligram of lead on each plate, setting free 1·0289 milligram of acid.

The Authors have experimented with some Faure cells of the 40 ampere-hour type, the active matter of which weighs 3 kilograms, and charged with 1 litre of water containing $\frac{1}{10}$ the volume of acid. The liquid then contains 184 grams of sulphuric acid, which to enter entirely into combination would require 388 grams of lead. Allowing that the accumulators receive 40 ampere-hours or 144,000 coulombs, this charge corresponds to the reduction of 155·8 grammes of lead on one of the plates, and the conversion into binoxide of an equal weight of sulphate from the other. The

quantity of sulphuric acid set free will then be 149·25 grams, or 3·73 grams per ampere-hour. For a charge of 40 ampere-hours the decrease of weight of the plates, and the increase of weight of the liquid, will be respectively about 150 grams. This motor force, proportional to the charge, is fully sufficient to indicate its variations, and even to register them.

In a trial the variation of weight was 138 grams. The concurrence is deemed by the Authors sufficiently close to base upon a system of weighting the liquid or the plates a method of registration of the charge.

P. H.

The Thermo-Chemical Study of Accumulators. By — Tscheltzow.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1458–60.)

To fulfil calculations of the electromotive force of accumulators by Joule and Thomson's law, $E = 0\cdot0436\ \Sigma Q$ (where E is electromotive force in volts, and ΣQ the heat, relative to the equivalents, in calories) it is requisite to determine the heat of formation of peroxide of lead from oxide of lead and free oxygen. This has been done by two different processes; (1) the action of nitrate of protoxide of mercury dissolved in dilute nitric acid on the peroxide of lead; (2) the action of anhydrous sulphurous acid on the peroxide. As means of four experiments (1) gave 31·85 calories, and (2) 82·62 calories; whence is calculable 12·14 calories (towards 17°) as a mean of both processes.

The heat of formation of peroxide of lead permits of the examination of the chemical reactions occurring on the two plates of an accumulator. There are four hypotheses examined. If $Pb\,O_2$ were reduced into Pb by the hydrogen at the negative pole, the reaction would disengage 37·20 calories, corresponding to 0·81 volt. If $Pb\,O_2$ were transformed into $Pb\,S\,O_4$, the disengagement of heat would be 81·50 calories, corresponding to 1·77 volt. If the negative lead were transformed into sulphate, and $Pb\,O_2$ into Pb, there would be disengaged 44·30 calories, corresponding to 0·96 volt. If there be sulphatation of the two electrodes, the heat disengaged will be 81·60 calories, corresponding to 1·93 volt, which the Author considers the true fundamental reaction.

P. H.

On the particular Properties of the Electric Current produced by the Rheostatic Machine. By Gaston Planté.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1338–1340.)

The flow of the electricity obtained by the aid of the rheostatic machine, discharged in quantity, presents particular properties, and permits of the production of effects that cannot be obtained

neither with voltaic electricity alone, nor with the ordinary apparatus of static electricity. These effects are at the same time mechanical and calorific, but the mechanical action is the more important. The Author has already pointed out the nodes of vibration formed in a platinum wire ($\frac{1}{20}$ millimetre) traversed by the current, the distance between these nodes varying with the electromotive force of the current.

The phenomena of piercing a thin condenser or plate of mica differ completely from those attending the discharge of the battery of 800 secondary couples. The mica, instead of being fused, is pulverised into lamellar fragments.

If a platinum wire in connection with one of the poles of the rheostatic machine (in quantity) is introduced into a capillary tube open at its two ends, one being immersed in salt water, and the liquid put into connection with the other pole of the machine, sparks accompanied by a crackling noise appear, and at the same time the liquid rises sharply in the tube, but the sparks succeeding with great rapidity, the liquid has not time to descend, and is elevated by steps to a height of 0·15 to 0·20 metre, according to the electromotive force of the current. Amongst the numerous analogies that exist between the phenomena produced by electric currents of high tension and mechanical effects, this resemblance to the hydraulic ram is one of the most singular. The Author explains by this action an occurrence during a thunder-storm at Ribnitz in 1884.

P. H.

On the Measurement of Re-directed Currents. By E. Hospitalier.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1456–8.)

In some electric machines the current takes an undulatory form, and when this is the case the readings of both ampere-meters and voltmeters are always lower than those corresponding to the true value of the electric energy of the external circuit. Trials were made with a Gerard dynamo in which the current passes the zero point four times in each revolution. The results were, that with the lamps at the same luminous intensity, the readings of an electro-dynamometer intercalated in the circuit remained the same, whether the currents were continuous or redirected. The readings of a Deprez-Carpentier ampere-meter were on an average 10 per cent. less with redirected currents than with continuous currents. Readings from a Thomson voltmeter, or from a Deprez-Carpentier voltmeter, put in shunt on the terminals of the machine were 15 per cent. less. Thus the form of current introduces differences that are not wholly negligible, for they lead to the attribution to a lamp fed by redirected currents of a consumption in watts 23·5 per cent. too small. The divergence shows that the readings of the ampere-meter are proportional to the mean quantity, and that the

square of the mean quantity introduced into the formula $W = R I^2$ for the calculation of the mean work per cent. is always smaller than the mean of the squares of the quantity deduced from the indications of the electro-dynamometer which represents the true expenditure of the lamp. In the voltmeter there is in addition the lowering of the reading due to self-induction. These experiments, show that large errors may be committed, in calculating the expenditure in watts for incandescent lamps fed by redirected currents, by taking the product of volts and amperes as read from magnetic measuring apparatus that have been calibrated with continuous currents. The quantity of current should be measured with an electro-dynamometer, and the difference of potentials with a quadrant-electrometer, or with a Cardew voltmeter.

P. H.

The Magnetic Potential due to a System of Coils. By G. LIPPMANN.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1533–4.)

The determination of the magnetic potential due to a coil supposes, generally, that the dimensions of each turn be known, and it is evaluated by an integration series; the final numerical approximation presents some difficulty. A particular arrangement will furnish the final result from a simple and exact formula. Suppose that instead of a single coil, three are taken parallel, α, β, γ; that these are set at the summits of an equilateral triangle, so that their axes may be the three sides of an equilateral triangle A B C. The Author states that the variation of the magnetic potential due to this system and taken from B into C is exactly equal to the product $4 \pi n i$, i being the quantity of current and n the number of turns carried by each bobbin. To demonstrate this, it is sufficient, the Author remarks, to observe that if the integral of the magnetic actions exerted by the coil α, considered singly, be taken along the contour of the triangle A B C, this integral is exactly equal to $4 \pi n i$. The action exerted by α on the side C A may be substituted by the action of γ on the side B C; similarly the action of α on the third side C A by the action of β on the side B C; so that the action of the system of the three bobbins on the side B C is equal to the sum of the actions exerted by α on the three sides of A B C, that is to say, to $4 \pi n i$. Thus in all measures where it is necessary to know *à priori* the integral of the magnetic actions due to a current i along a finite right line B C, the system of three coils may be employed, and it will be simpler than that of one coil. The demonstration applies without difficulty to the case of a regular polygon of n sides.

P. H.

The Electric Conductivity of Water Distilled in a Vacuum. By FRIEDRICH KOHLRAUSCH.

(Centralblatt für Elecktrotechnik, vol. vii., 1885, p. 15.)

The Author has found that the electric conductivity of water distilled in a vacuum is much less than that given by previous experimenters. The apparatus for this research consisted of a glass retort of 100–200 centimetres capacity, communicating by means of a glass tube with a smaller vessel or receiver for the distillate to be tested for electrical resistance. Two platinum electrodes, each of about 5 square centimetres effective service, are fitted into the receiver. A suitable quantity of very pure water is poured into the apparatus through a glass supply-pipe, which is then connected with a mercurial air-pump, and the glass vessels exhausted until the water contained therein boils. As soon as the ebullition ceases, evaporation is allowed to take place slowly for about a quarter of an hour under a moderate temperature, whilst the distilling apparatus is kept continually agitated, the aqueous vapour being absorbed by cooled sulphuric acid. To admit of this agitation, the connection with the air-pump is made by means of long bent glass tubes. The exhaustion attained is equivalent to about 0·01 millimetre of mercury. The supply-pipe is then melted off and the vessel hermetically sealed. The apparatus now contains sufficient water to fill the larger vessel to about two-thirds of its capacity. A heating bath of 30° to 40° Centigrade, and a cooling bath of 0° to 8° Centigrade are now employed for distilling over the 6 to 8 centimetres of water into the receiver. For measuring the resistance of the distillate a Wheatstone's bridge, a sensitive galvanometer with a rapidly vibrating needle, and two Smee's galvanic cells are employed. The resistance of a distillate in a vacuum is found to decrease after an interval of time. Taking the resistance at 700,000 Siemens' units five minutes after the distillation is completed, it becomes 400,000 in ten minutes, 250,000 in one hour, 90,000 in three hours, and 28,000 in fifteen hours, or one twenty-fifth of the initial value. The Author concludes from his experiments that the conductivity of water at 18° Centigrade is 25×10^{-12}, or in the ratio of 1 to 4×10^{10} of that of mercury; so that a thread of quicksilver laid around the earth would have the same resistance as that of a thread of water having the same cross-section and a length of 1 millimetre.

J. J. W.

On the Electric Conductivity of Solid Mercury and of Pure Metals at low Temperatures. By Messrs. CAILLETET and BOUTY.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1188–91.)

The electric resistance of pure metals increases with the temperature. According to the experiments made by Matthiessen and

by Benoit, the mean coefficient of increment of resistance for a degree of temperature between 0° and 100° varies little, with one metal or another, from $\frac{1}{273}$, that is, from the expansion coefficient of gases. If the same law continued to apply at lower temperatures, the resistance of a metal, varying as the pressure of a perfect gas at constant volume, would furnish a measure for the temperature, and would become nil at absolute zero.

Mercury.—Mascart's empirical formula, for the apparent resistance of mercury in glass below 0° is applicable as far as the temperature of congelation. In solidifying, mercury becomes a better conductor in a ratio, which at −40° is equal to 4·08. The resistance of solid mercury decreases thereafter regularly with the temperature; it is accurately represented between −40° and −92·13° by the formula:—

$$r_t = r_{-40} \frac{1 + a\,t}{1 - 40\,a},$$

where t represents the temperature Centigrade, with $a = 0\cdot00407$.

Silver, aluminium, magnesium, tin.—For these several metals the resistance is represented by the formula:—

$$r_t = r_0\,(1 + a\,t),$$

and the values of a (deduced from numerous experiments at several temperatures) are the following:—

Metal.	a.	Limits of Temperature.
Silver . . .	0·00385	+29·97° to −101·75°
Aluminium . .	0·00388	+27·7° „ −90·57°
Magnesium . .	0·00390	0 „ −88·81°
Tin	0·00424	0 „ −85·08°

Copper.—The most complete experiments were those with copper; the results are deduced from thirty trials, distinguished in three groups.

	a.	Limits of Temperature.
Copper . . .	0·00418	0° to −58·22°
	0·00426	−68·65° „ −101·30°
	0·00424	−113·08° „ −122·82°

The variation of resistance is of nearly absolute regularity, and the values of a are very close to those obtained, for near 0°, from the formulas of Matthiessen and Benoit.

Iron, platinum.—These two metals are distinguished from the others by the variation of their resistances below zero. The formula last given still holds good for iron from 0° to −92° with $a = 0\cdot0049$; but it does not apply to platinum, for which the value of a, deduced from this formula, would be, near 0°, about 0·0033, increasing as the temperature falls, and becoming 0·00342 for an inferior limit, equal to −94·57°; then it approaches the other pure metals as the temperature decreases.

The Authors' experiments prove that the electrical resistances

of pure metal generally decrease regularly when the temperature is lowered from 0° to −123°, and that the coefficient of variation is nearly the same for all.

P. H.

Increase of Temperature in a Wire due to the Passage of a Strong Current. By G. OELSCHLAEGER.

(Elektrotechnische Zeitschrift, 1885, p. 93.)

A copper strip 2 metres long, 10 millimetres broad, and ½ millimetre thick, is stretched in a horizontal plane, and a thermopile 3 × 2 × 2 millimetres composed of iron and german silver, is placed thereon about midway between the supports. Currents up to 15 amperes are passed through the strip, and the increase of temperature of the latter noted. As the thermopile is small in comparison with the band, the temperature of one may be taken as equal to that of the other. On changing the direction of the main current, that of the thermopile was found not to alter, thus proving the absence of any derived current. The rise of temperature t is proportional to the square of the current-strength, or

$$t = \frac{1}{45} J^2.$$

By means of the temperature coefficients determined for the copper strip and the wires used in the Author's experiments, the percentage increment of resistance $\frac{100 \Delta W}{W}$ of the strip could be calculated from the equation—

$$\frac{100 \Delta W}{W} = 0 \cdot 00402 J^2.$$

where W is the resistance of the strip and Δ W the increment.

The wire w to be experimented with and the strip W are joined together, and put in circuit with two high resistance rheostats R R′, a mirror-galvanometer and a dynamo-machine, so as to form a Wheatstone's bridge. One terminal of the galvanometer in the centre diagonal is connected with the point of junction of the wire and strip, the other terminal being joined to the arms containing the rheostats. The outer diagonal contains, in addition to the current generator, an electro-dynamometer. A balance is first obtained by passing a weak battery-current through the bridge and altering the resistance of R, the final value of which is noted. Currents of different strengths to a maximum of 15 amperes are then used, and the resistance of R increased in each case until a balance is again established, the value R + Δ R being recorded. The increment of resistance Δw of the wire under test (of initial

resistance w) can then be calculated for each current strength from the equations

$$w = \frac{W\,R}{R'},$$

and
$$w + \Delta w = \frac{(W + \Delta W)\,(R + \Delta R)}{R'}.$$

These two equations combined as below give the percentage increments of resistance of w, R and W respectively.

$$\frac{100\,\Delta w}{w} = \frac{100\,\Delta R}{R} + \frac{100\,\Delta W}{W}.$$

In the Paper the results are tabulated, and the Author's experiments have confirmed the observation of Professor Forbes that a given wire, when acted on by the same current strength, is heated about 3½ per cent. less when covered with gutta percha than it is when bare, and a similar difference, amounting to about 2·9 per cent., is observed in the case of silk-covered wire. The Author remarks that, as regards the latter, the difference may be due to the larger radiating surface offered to the atmosphere on account of the inequalities of the covering and the projecting fibres of the silk.

J. J. W.

Gellerat's Electric Road-Roller. By — Giraud.

(Comptes rendus de la Société des Ingénieurs-civils, Paris, 1885, p. 320.)

Towards the end of 1883, Mr. E. Gellerat made a successful application of dynamo-electric power to drive a road-roller. He adapted the electric machinery to the framing and roller of an existing steam-roller, from which the boiler and machinery was removed, leaving a platform about 18 feet long and 6½ feet wide, carried on cast-iron rollers 4 feet and 4½ feet in diameter, weighing in all from 10 tons to 11 tons. On this platform, in three stages, 104 Faure accumulators, weighing about 130 lbs. each, were deposited, making a load of about 6 tons. The dynamos and the machinery weigh about 1 ton. Together, the gross weight of the road-roller amounts to 18 tons. Steam-cylinders for the same weight work to from 10 HP. to 15 HP., and to much more on an emergency; and for this power two Siemens dynamos of the type D^2 on one shaft are provided, capable of exerting 12 HP., and more than that by increasing the velocity. A small dynamo, type D^1, of 1¼ HP., is supplied for the steering power.

The motion of the dynamos is reduced and transmitted by suitable gearing to the intermediate shaft, whence it is transmitted in the usual manner to the rollers. The accumulators have each a power of about 2 volts, making together about 200 volts. Seven-

teen accumulators were reserved for the steering when it was necessary. The remainder were employed, more or less, for locomotion; but, on firm ground 50 accumulators sufficed for this purpose, with an intensity of current of from 30 to 40 amperes, representing from 4 HP. to 5 HP., although the speed attained did not exceed $1\frac{1}{4}$ mile per hour.

The roller was taken over some newly-laid macadam of a thickness of from 8 inches to 10 inches, bedded on a clay sub-structure, over a newly-constructed sewer, on an incline of from 1 in 50 to 1 in 33. All the accumulators were brought into action; the rolling commenced at a speed of from 2 to $2\frac{1}{2}$ miles per hour, and was continued for three hours with as much facility as if the machine had been worked by steam. The expenditure of electricity was proportional to the resistance of the ground. The intensity of the current averaged 35 amperes, and attained at one point to 75 amperes, which for 104 accumulators, corresponded to the work of 20 HP. At the end of the trial, which was satisfactory, the accumulators had worked for four hours, and were not half discharged.

D. K. C.

Influence of Storms on Subterranean Telegraph Lines.

By — BLAVIER.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 1534–5.)

When the construction of the long subterranean lines in France was commenced some years ago, it was thought that their conductors would be quite free from the effect of storms. Accidents are much rarer than with aerial lines, but that they do occur was evidenced by the violent storm on the 9th March at the middle of the underground line connecting Belfort with Besançon, when sparks appeared at the two extreme stations. This phenomenon, apparently contrary to the theory of static electricity, the Author thinks may be explained either as an effect of electro-dynamic induction or as an effect of electro-static induction. If the cable is buried only to a small depth in a badly-conducting earth, the sheathing takes, under the influence of storm-clouds whilst the internal wire remains neutral, a more or less considerable electric charge. At the discharge of the clouds this charge becomes free, and escapes into the earth following the sheathing in two opposite directions. This will develop in the interior conductor two induced currents of contrary directions, the difference of which will act on the apparatus at the end stations. Or the conductor may charge itself from the earth-plates and lightning-guards under the influence of this sheathing-charge.

P. H.

A Photometer for Electric Light. By J. WYBAUW.

(Bulletin de la Société Belge d'Électriciens, vol. ii., January 1885, pp. 5–12.)

The Author proposes to find a means of overcoming or diminishing the difficulty met with in ordinary photometers for the direct comparison of the electric light with the flame of a Carcel lamp or gas-burner. The difference of colour in two such lights is so considerable as to render the accuracy of such an operation uncertain. Using Foucault's photometer, the comparison is nearly impossible; with the Bunsen photometer the difficulty is somewhat less, because by experience one can tell pretty exactly the moment when the edge of the little translucent spot becomes vague and disappears more or less. In any case the uncertainty is great, and the results vary with the observer, and even between two sets of observations by the same person.

Let unit of illumination be that furnished at unit distance by a source equal to the light of unit intensity. The curve representing the illuminations given by this source at different distances from the origin would be $y = \frac{1}{x^2}$, and for a source of intensity I, it would be $y = \frac{I}{x^2}$; so that by making $x = 1$ in the equation to the curve of illumination of a source, there is obtained an ordinate $y = I$, which contains as many units of illumination as the source does of units of intensity. To compare two sources, I and I′, it suffices to consider the differences between the ordinates of the two curves of illumination at the same horizontal distances from the origin. This consideration led the Author to construct his photometer, which consists of two mirrors, m and n, some distance apart, and inclined at 45° to the rays of light coming from the source O. These rays are reflected on two screens p and q, perfectly alike, and formed of white paper. The whole is fixed in a rectangular box 50 centimetres long by 40 wide, blackened inside and provided with screens, to prevent useless diffusion and reflection of light. The observer ascertains when the screen p is more lighted than q. The difference of the two illuminations can be measured with another known light, C, by which the illumination of the screen q is increased until it is equal to p; or inversely if C remain fixed, the source O can be moved backwards and forwards until equality is established. If O is an electric light, the screen q is illuminated by rays of electric light, but at the same time by a small portion of yellow light from the carcel lamp C, to make the tints on screens p and q alike. The intensity I of the source O is given with great accuracy by a general formula, which may be simplified to the form

$$I = y\,\frac{z^2}{x^2}$$

where x denotes the distance O m p, and z the distance C q, to be

measured for each experiment. On the cover of each photometer there is a curve which gives the value of y for any value of x whatever.

If x = constant, the intensities I and I′ of the two sources by the general formula are $M\frac{C}{z^2}$ and $M\frac{C}{z'^2}$, where $\frac{C}{z^2}$ and $\frac{C}{z'^2}$ express the differences of the illuminations in p and q. This gives an easy means of comparing the intensities of different sources by a lamp of type C. One advantage of this photometer is that it is possible to measure an electric light in a confined space. Calculations are easiest with C constant, but this condition is frequently difficult to realise practically. The Author investigates the various formulæ, and works out several numerical examples.

Transparent screens p and q could be employed as in Foucault's photometer; and another less practical arrangement is given, resembling Bunsen's photometer.

The method employed by the Author to realise the greatest equality of colour on the screens does not lead to any likelihood of error due to the diminution in the lengths of the distances compared. In this, as in ordinary photometers, it is the distance z of the standard light from the screen which determines the result of the operation. Numerical examples are given to show that errors of observation do not affect the results more seriously in this photometer than in that of Foucault or Bunsen, whilst by the plan of illuminating one screen with a light three-quarters to four-fifths that of the other screen, the distances are very much diminished, and, the colours being brought to the same tint, the errors are reduced to a minimum. The use of coloured glasses or solutions interposed between the eye and the images on the screens, renders the tints really equal; but this expedient is useless here, and can only destroy the correctness and delicacy of the observations, by rendering the little differences less sensible.

W. R.

Photometry of Intense Foci of Light. By A. Crova.

(Comptes rendus de l'Académie des Sciences, vol. xcix., 1884, pp. 1067–69.)

A complete determination of the photometric value of an intense focus of light, electric or solar, requires the practical realisation of the following conditions: (1.) Comparison of two lights of different tints. (2.) Evaluation of the tint by means of a numerical factor. (3.) Determination of the photometric ratio of a very intense source in function of a relatively feeble standard.

The first may be resolved by one of two methods previously described[1] by the Author, which admit of reducing the com-

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[1] "Comptes rendus de l'Académie des Sciences," vol. xciii., p. 519; and vol. xcvi., p. 1271.

parison of the total lights to that of the relative intensity of a simple light, conveniently chosen, taken in the two sources; the more simple consists in the use of a solution of perchloride of iron and chloride of nickel, through which a photometric screen is observed.[1] With a thickness of about 7 millimetres this solution stops all but radiations comprised between wave-lengths of 630μ and 534μ, with a maximum towards 580. The simple radiations transmitted with maximum of intensity chiefly include all those giving the same ratio as that of total illuminations with the standard Carcel with relation to the luminous sources, the tint of which varies between the reddest, that of the Carcel, and the whitest, that of solar light. In the second case the Author has shown[2] how the use of the spectro-photometer admits of expressing the temperature of a luminous source in arbitrary optical degrees. In practice, the tint may be easily represented by means of two successive photometric determinations; one, obtained by observation of a Foucault photometric screen through the 580 solution, gives the ratio of the intensities; the other, made by placing before the eye a red (protoxide of copper) glass which allows of the passage of radiations included between 726μ and 752μ, with a maximum at 650μ, gives a ratio as inferior to the preceding as the tint of the light compared to the Carcel is whiter. The quotient of the first determination by the second admits of characterising the tint; it is greater as the light is whiter; it is equal to unity for sources of the same tint as the Carcel. For a glow-lamp it varied, during the Author's experiments, from 1·05 to 1·23, according to the intensity of the current, whilst the luminous intensity was raised from 1·1 to 3·2 Carcels. For arc-lamps the coefficient representing the tint is greater; it attains the value 1·5 to 1·7, with a Serrin lamp carrying Carré carbons of 12 millimetres in diameter, fed from a "workshop" Gramme dynamo, giving 230 to 320 Carcels intensity, and expending between the points an electric work of 150 to 166 kilogram-metres per second. Greater intensities will probably be represented by higher numbers.

With sunlight the tints are represented by numbers increasing with the height of the sun, and greater than the preceding.

The Author proposes to follow the working of incandescent lamps with relation to the electric energy expended, and to stop

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[1] The most suitable solution is the following:

	Grains.
Perchloride of iron, anhydrous and sublimed . .	22·321
Chloride of nickel, crystallized	27·191

dissolved in distilled water to a total volume of 100 cubic centimetres at 15°. To avoid all possibility of reduction of the perchloride of iron, the solution, saturated with chlorine, is enclosed in a cell formed of a ring of ground glass, against which are pressed two sheets of glass by means of a frame of blackened brass provided with screw pressure.

[2] "Comptes rendus de l'Académie des Sciences," vol. xc., p. 252; and vol. xcii., p. 70.

the degree of incandescence and of whiteness of the light at a higher limit expressed by a numerical coefficient that determines the best conditions of intensity and of whiteness compatible with sufficiently long life of the lamp.

P. H.

An Apparatus for Indicating the Speed of Motors.

By G. Hochschild.

(Centralblatt für Elektrotechnik, vol. vii., 1885, p. 90.)

On a base-board, mounted in a suitable iron standard, is a small governor kept in rotation by means of a strap or band from the shafting, the speed of which has to be kept under control. To the governor is attached a lever, which is connected to a pointer that makes contact with three metal plates insulated one from the other. On these plates are inscribed the words "stop," "medium speed," "too fast." One pole of a galvanic battery is joined to the axis of the pointer, the other pole being connected with three electro-magnetic signal disks, which are in circuit with the contact plates. Each disk bears on its face an indication corresponding to that on the plate with which it is joined. When the shafting is not in motion, the pointer rests on the plate marked "stop." Directly the speed of the shafting becomes too great, the action of the governor causes the pointer to make contact with the plate inscribed "too fast;" a current then passes through the indicator and brings into view the corresponding signal-disk. In places where the indicating-board cannot be kept constantly under supervision, alarm-bells can be put in circuit with the disks.

J. J. W.

Heavy Rainfall at Vienna, 15th and 16th May, 1885.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 6 June, 1885, p. 214.)

On May 14th a deep cyclone from the Western Mediterranean was passing over South France and Upper Italy in a N.E. direction. On the 15th at noon its centre was over Vienna, with the barometer at 28·6, and almost no wind. Cold masses of air poured in from the north and west to the area of depression, reducing the temperature almost to zero, and causing a very heavy fall of snow and rain. The rainfall for the day in Zurich was 0·71 inch, Salzburg, 0·98 inch; Munich, Bregenz, and Ischl, 1·26 inch; and in Vienna, 5·97 inches.

On the morning of the 15th the wind varied between E.N.E., N.E., N.N.E., and N.; after the passage of the storm-centre, it

went into the west and blew continuously thence for thirteen hours. It is to be remarked that though this is the highest rainfall noted in Vienna, the hourly rainfalls only reached 0·51 inch and 0·55 inch, which have been exceeded in 1853 (0·86 inch); 1854 (0·83 inch); 1855 (0·75 inch); 1881 (1·14 inch); and 1882 (1·10 inch).

The greatest rainfall for twenty-four hours recorded in Vienna prior to this storm was 4·09 inches.

W. B. W.

Influence of Mountains on Temperature, Rain and Wind.

By Dr. Julius Hann.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 7th March, 1885, p. 102.)

The highest point in the Alps as to which meteorological observations for a whole year are available is the Theodul pass, 10,925 feet above sea-level. These observations were taken August 1865 to August 1866. The coldest month (January) showed a mean temperature of 9° Fahrenheit, the hottest (July) 34·7°, while the mean temperature of the whole year was 20·5°. In Vienna the mean temperature for January is 29·5°, July 68·5°, and for the whole year 49·5° Fahrenheit. In the following Table the temperatures refer to the period 1851–1880:—

Place.	Height above Sea.	Mean Temperature (Fahrenheit).		
		January.	July.	Whole year.
	Feet.	°	°	°
Theodul pass	10,925	9·0	34·7	20·5
Goldzeche Fleiss	8,990	16·0	40·3	27·9
St. Maria (Stelvio)	8,235	13·5	45·1	28·9
St. Bernhard	8,130	17·1	44·2	29·3
Säntis	8,097	16·0	42·1	28·4
Bergbau, Schneeberg . . .	7,776	13·3	45·9	29·3
Obir	6,716	19·9	48·7	33·1
Schmittenhöhe	6,348	19·2	48·2	33·3
Vent	6,168	17·4	48·6	33·3
Sulden	6,037	19·2	51·1	34·7
St. Christof (Arlberg) . . .	5,873	16·9	50·0	33·3
Schafberg.	5,840	22·5	49·8	35·4
Sea-level (Isotherm of Alps) .	..	32°–28·4°	69·8	51·8
Average decrease of temperature per 100 metres (328 feet) .	..	0·59	1·22	1·03
		Feet.	Feet.	Feet.
Increase in height for decrease in temperature of 1° Fahr. .	..	547	273	318

By comparing these figures it is seen that as a rule the tops of mountains have milder winters than the valley stations, and that

the summer is cooler than at valley stations of the same height. In certain large regions of the Alps it may be taken to be true that the temperature decreases in arithmetical progression according to the increase in height. This decrease is different at different seasons (see Table), being much less in winter than in summer.

In connection with this question of decrease of temperature, an attempt has recently been made to find the zone where the winter frosts cause the greatest disintegration of rocks. Observations in the Alps give this as from 4,000 to 4,600 feet above the sea-level.

The limit of perpetual snow in the Alps is from 8,800 to 9,200 feet above sea-level. As regards the lying of snow at lower levels there are few data. Tänzler has made observations on the lying of snow at Säntis, and finds that it lies for

77	days at a	height of	2,130	feet.
200	„	„	4,265	„
245	„	„	6,400	„

The condition of temperature of the high Alps are often compared with those of the Polar regions; such comparisons are misleading, for although the mean temperature of the year may be about the same, that of the individual months is very different. Turuchansk, in Siberia, 66° N. lat., has the same mean annual temperature as the Theodul pass, but its mean for January is 14·1° and for July 60·1°, as compared with 9° and 34·7° respectively. The arctic temperatures are much lower in winter and higher in summer than those of the High Alps. A July mean of 34·7° (Theodul pass) is, so far as we know them, not to be found in the Polar regions. This is how it is that in Siberia with a mean annual temperature, which in the Alps renders vegetation impossible, there are flourishing forests.

It is known that in general the rainfall increases with the height, but the increase cannot be reduced to formula, as local conditions are all important. It is to be noticed that the rainfall only increases to a certain height, and then decreases again. The reason of the greater rainfall in mountains is to be sought in the fact that the mountains are a mechanical hindrance, and force the air-currents to rise. As the air rises it expands, and therefore cools. This dynamic cooling is the chief cause of such rains, and not the mixing of cold and warm layers of air. When the air first cools the rain is heaviest, and the more it cools the lighter the rain. This probably accounts for the fact that in the high regions of the Alps the snow falls only in fine ice needles. The increase of rain with increased height is due to the greater frequency of showers. The intensity decreases with the height, but the duration of the rain increases. The zone of greatest rainfall in the Himalayas is at about 4,600 feet above the sea. That of the Alps is not determined. The following Table shows the distribution of rain on both sides of the Arlberg:—

—	Arlberg.		Percentage of Rainfall at Bludenz.		
	Height above Sea.	Rainfall.	Whole year.	Winter half.	Summer half.
	Feet.	Inches.			
Bludenz	1,837	46·8	100	100	100
Klösterle	3,478	59·4	127	140	121
Langen	4,003	72·0	154	180	144
Stuben	4,593	72·8	155		
St. Christof	5,873	74·4	160	193	142
St. Anton	4,200	46·8	100	116	91
Landeck	2,657	24·0	51	44	53

This Table shows that the rainfall increases with the height at first very quickly, and afterwards more slowly. The zone of greatest rainfall in the Alps is probably at about 6,500 feet above the sea.

Some particulars are given as to the air-currents in the Arlberg Tunnel, and they are shown to depend upon the differing levels of the valleys at each end of the tunnel, the Rhine valley being 1,400 feet, while the Inn valley at Landeck is 2,600 feet above the sea-level. The level of the tunnel itself is about 4,300 feet above the sea. It is shown that it is a favourable condition for the natural ventilation of a tunnel that its ends should open into valleys of different depths.

W. B. W.

Notes upon the effect of the Waves upon the Neapolitan Shore in connection with the new Coast Works.

(L'Ingegneria civile e le Arti industriali, 1885, p. 53.)

During the last fifteen years an extensive sea-wall has been constructed at Naples, by means of which a large area of land has been reclaimed and laid out for buildings, public gardens, and esplanade. This Paper gives an account of the works, and of observations upon the action of the sea made during their progress. The wall is founded upon concrete laid between two rows of piles, and presents a deeply concave surface to the sea. The toe is protected by a mass of stone blocks of about five tons weight each, thrown down so as to form a flat slope in front of it. The height of the wall varies from 7 to 16 feet.

Action of the Sea in effecting the movement of the Sand.—The movement and accumulation of the sands may be effected either by wave-motion or by currents. In the Gulf of Naples it is to the former that the movement is due, which agrees with Cialdi's theory that "it is the wave-motion which moves and transports the sands." There is in the Mediterranean a littoral or surface current moving constantly from left to right of a spectator

standing on the shore and looking towards the sea. The velocity of this current seldom exceeds 3 or 4 miles per hour. Its width is about 3 miles. It does not generally enter gulfs or narrow bays; it is variously affected by the wind, and is not perceptible at the bottom; it is, however, sometimes driven into gulfs by the wind, and may traverse them in a contrary direction when the wind is in certain quarters. This current is further described in the Paper, as also are the prevailing winds, the movements of the shore, and the various works which have from time to time been constructed in the gulf. The Author states as the result of the observations made by himself and others, that the littoral current from left to right produces no effect in transporting material; on the other hand, considerable movement is caused by the waves, which excavate the sand when the wind is strong and deposit it when light. As strong winds are less frequent than light, and as the quantity of sand which can be furnished by the natural deposits from the products of the sea is considerably greater than that furnished by the detritus coming from the land,[1] the resultant is an increase rather than a diminution of the shore.

The following are the Author's conclusions as to wave-action :—

(*a*) Whatever theory may be entertained as to the origin of waves, this fact is undisputed, that near the shore the vertical motion is transformed, as the depth diminishes, into a more or less rapid horizontal movement of translation.

(*b*) By reason of this transformation the waves acquire a horizontal action upon shallow shores, which is at times very energetic, causing them to break violently against any obstacle they may encounter. The transformation may be either partial or complete, forming either bottom or surface waves, or a motion of the whole fluid mass.

(*c*) The depth at which the wave-motion is sensible, and produces action upon the bottom, is considerably greater than the maximum height of storm waves.

(*d*) If the waves strike normally, or nearly so, upon a vertical or very steep surface, they mount up to a great height, and then in falling produce erosion and excavation.

(*e*) When a strong wind drives the sea continuously straight against the shore, this becomes excavated to a greater depth; if, however, the wind is weak, the waves are developed gently and run up along the shore, and by depositing the matter they carry with them, raise it in the form of a sand-bank or bar, which in many places forms the base of a dune.

(*f*) If the wind is oblique, instead of excavating, the sea exercises a transporting force, which is greater when the direction of the wind makes an angle of 45° with the shore, and especially if

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[1] As the result of observations and analysis it is stated that in the Mediterranean out of every 100 parts of sediment 20 are due to the washing away of the shore, 30 to the deposits brought down by streams, and 50 to subaqueous organic matter. In the Adriatic these proportions are respectively 5, 35, and 60.

there is a current in the same direction. If these two forces act in opposite directions, opposite effects may be produced, and there may even be no motion of the matter held in suspension, in which case sand-banks will be formed.

With reference to the concave section of wall, the Author quotes the opinions of Colonel Emy, who in his work "Du mouvement des ondes et des travaux hydrauliques maritimes," states that the section should be such as to convert by degrees the horizontal roll of the waves into a vertical motion. The objects of such walls are: (*a*) to hinder the development of waves on the bottom; (*b*) to prevent the mass of water, driven forward by its own energy, from striking violently against the wall, as it would against a vertical face; (*c*) to cause the waves to roll back into the sea without breaking over the top of the wall. To obtain these objects the wall should rise gradually from the bottom without any abrupt face. It should present an extended surface to the waves, so that their whole energy may be expended before reaching the top, and the curvature should be such that the waves may pass down into the sea. There should be no projecting cornice within reach of the waves. The particular form of curve is a matter of indifference (it may be circular, elliptical, cycloidal, or spiral) so long as it is tangential to the sea-bottom. Applying these principles to the wall at Naples, it appears that where the height exceeds 13 feet it is sufficient to destroy the force of the waves, except during the most violent storms; but when the wind is very high the waves break over the top and pour over the parapet, or, rising vertically, are blown across the roadway. It is, however, only the lower portions of the wall that are injured by this action. To reduce the injurious effect, the rockwork at the base of the wall has been raised above mean sea-level, so that the waves break upon it before reaching the wall. This rockwork, however, subsides, and leaves the vertical base of the wall exposed to the action of the waves, which destroy the piling and undermine the concrete foundation. A series of diagrams is given, showing the effect produced upon waves by the wall. The Author's opinion is that the general principles upon which the wall was designed are sound, but that modifications should have been introduced. At the high part, which is founded upon compact tufa, the curve at the bottom should have been very flat, and tangential to the bed of the sea. Rockwork was not required here. At the lower parts, however, which are founded on sand, a mass of rockwork should have been thrown down, having a flat slope to seaward and a level berm, about 3 feet above sea level in front of the wall.

Upon several occasions during construction, and since its completion, the wall has suffered severe damage. On the night of the 3rd of December, 1872, a heavy sea, driven into the bay by south-east and south-west winds, overturned a length of about 2,000 feet of wall. Upon the same occasion a large coping stone—measuring 3 feet 6 inches by 2 feet 2 inches by 1 foot 2 inches, and weighing

half a ton—was hurled across the road to a distance of 98 feet. The force exerted upon the stone is calculated to have been 24 foot-tons. The conclusions to be drawn from the disasters which occurred are that upon a hard bottom waves develop enormous energy by reaction; that when the sea is driven by strong winds between resisting obstacles, it acquires a very powerful momentum; that in such situations it is useless to attempt to secure the stability of walls by giving them excessive thickness; the aim of the engineer should rather be, by laying out the work in suitable directions and carefully designing its form, to avoid the direct action of the waves.

During the winter of 1875–6 two violent storms occurred, the first destroyed a length of 280 feet of wall, the second a length of 260 feet. The wall, violently broken away from its foundation, was thrown over in great masses, the largest of which was about 53 feet long, and weighed 280 tons. This destruction was due partly to the wall being in an unfinished condition, partly to the mortar not having properly set, partly to a long duration of stormy weather culminating in very severe gales. The Author attempts to calculate the force necessary to have produced these effects. He adopts several hypotheses as to the conditions under which the wall was overturned, and finds a minimum value in each case for F, the force in tons per square foot upon a vertical projection of its face. In the first case, he supposes the greatest mass, 53 feet long, to have been at one blow separated from the rest of the structure and overturned. The force required in this case would have been $F > 5$ tons. In the second case, he assumes that breaches had been made at each end of the mass by previous force of the waves, in which case F must have been $> 3 \cdot 8$ tons. After finding the value of F upon several other suppositions, and examining in detail the whole series of values thus formed, the Author comes to the conclusion that the actual value must have been between 2 and 3 tons per square foot. The force of the waves in severe storms has been calculated by other engineers, thus:—Cialdi, at Civita Vecchia, estimated it at $1\frac{1}{2}$ ton per square foot; Bonin, at Cherbourg, $1\frac{3}{4}$ to $2\frac{3}{4}$ tons; Regy, at Cette, (from the displacement of masses of 850 and 8,930 cubic feet,) $\frac{3}{4}$ of a ton to $1\frac{1}{8}$ ton; Stevenson, at Skerryvore, $2\frac{3}{4}$ tons; La Ferme, 2 to $3\frac{1}{2}$ tons; Milesi, at the St. Vincenzo breakwater at Naples, 1 ton; Voisin Bey estimates that in the ocean the force sometimes reaches $2\frac{3}{4}$ tons, in the North Sea and Mediterranean from $1\frac{1}{3}$ to $1\frac{3}{4}$ tons; but that generally speaking it does not exceed $\frac{1}{2}$ a ton per square foot.

The Author concludes by insisting upon the importance of using cement of high tensile strength in sea-walls, as upon this, even more than upon the specific gravity of the stone employed, the stability of the work depends.

W. H. T.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1884–85.—Part III.

LONDON:

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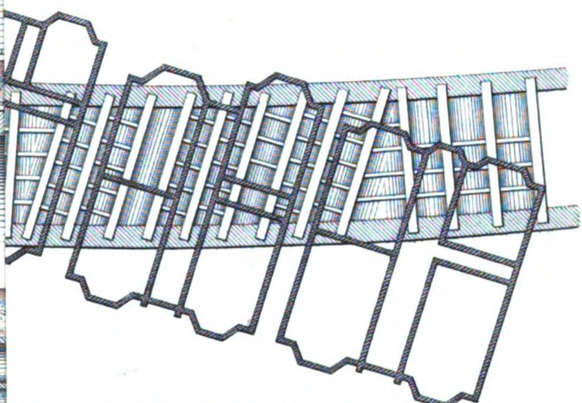
STAMFORD STREET AND CHARING CROSS.

PLATE. 1.

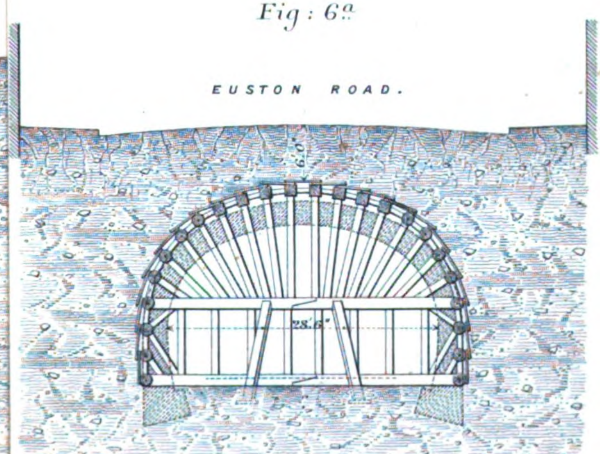
Fig: 24a



NDER PEMBRIDGE SQUARE HOUSES.

Scale of Feet. 30 40 50 60 70 80 90 100 Feet.

Fig: 6a



TIMBERING OF TUNNEL.

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.

PLATE. 2.

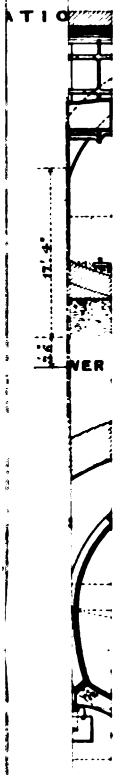


Fig : 24.

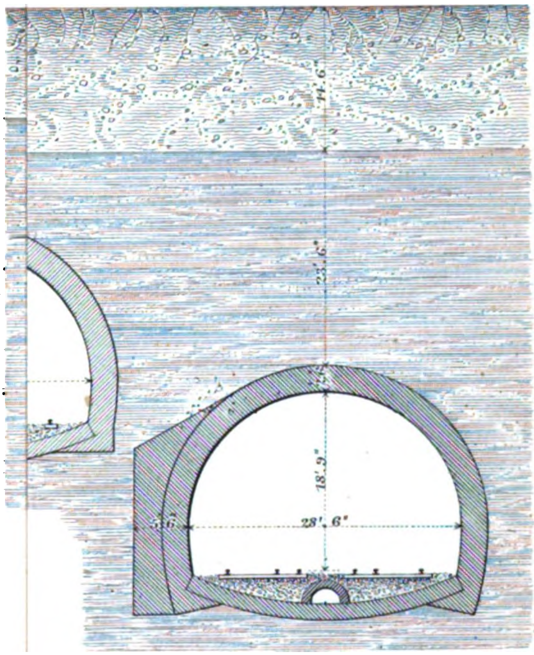
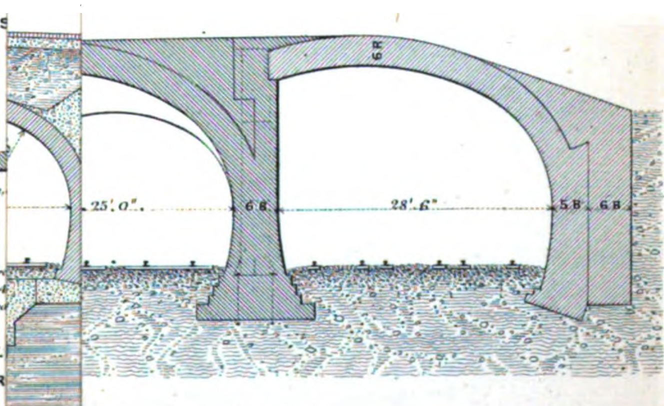


Fig : 25.



MOUTH AT KINGS CROSS.

THO^s KELL & SON. LITH 40 KING ST COVENT GARDEN.

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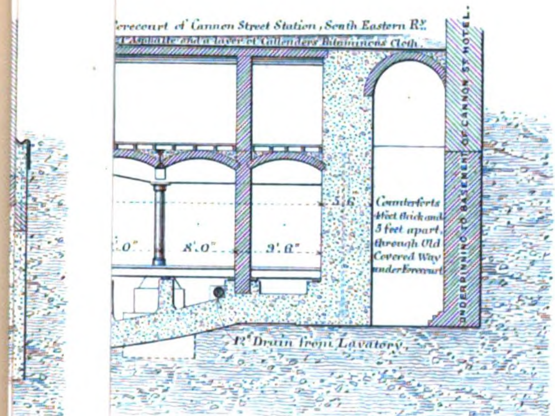
PLATE 3.



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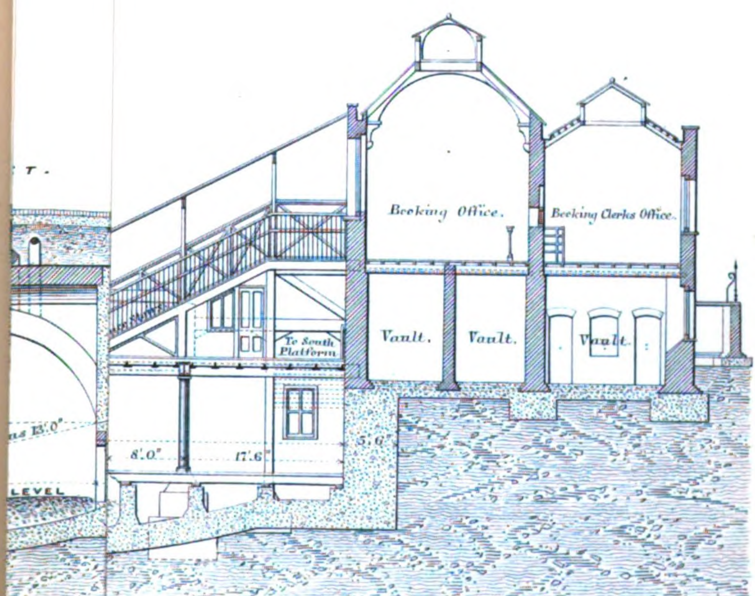

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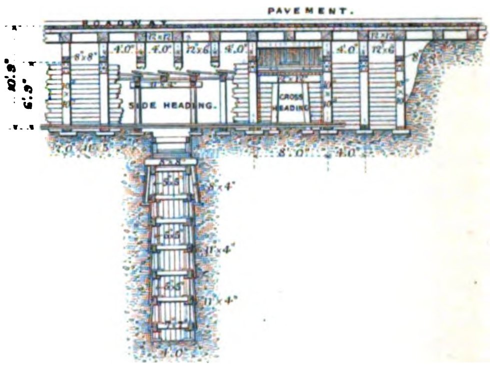
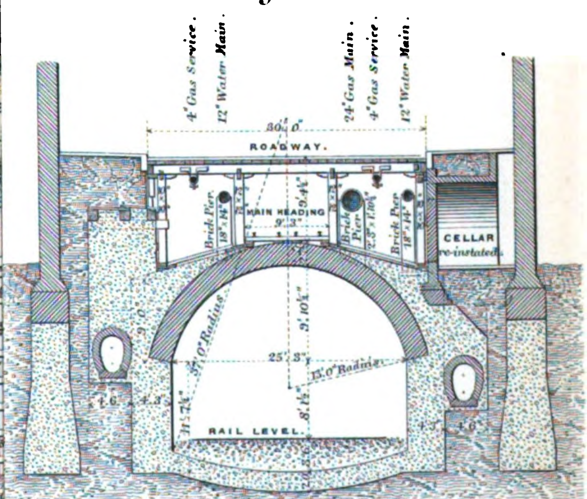
PLATE 4.

Fig: 24.



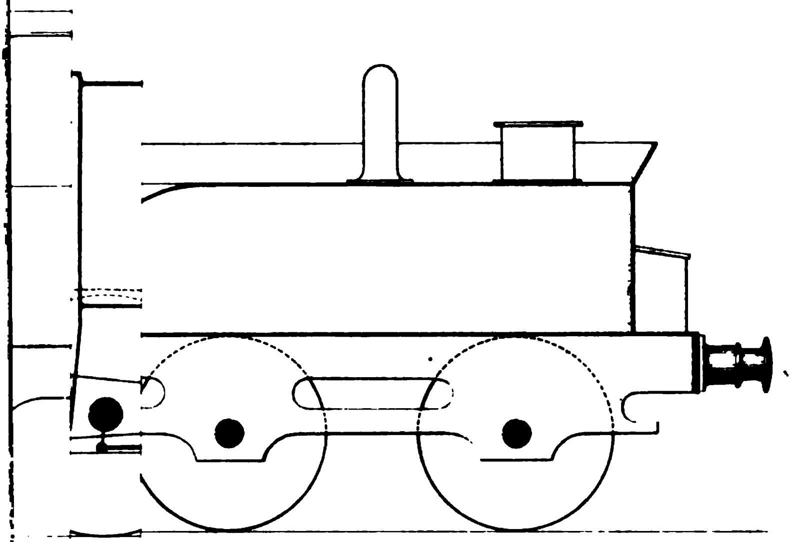
SIDE HEADING AND UNDERPINNING.

Fig: 26.



TUNNEL COMPLETE.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN



. . . 13 Tons 14 Cwts.
. . . 14 " 0 "
. . . 12 " 13 "
Total: 40 " 7 "
l. and 11 Tons 6 Cwts. of Water . . . 28 Tons 0 Cwts.
. . . 2550 Gallons.
'ender in working order . . . 68 Tons 7 Cwts.

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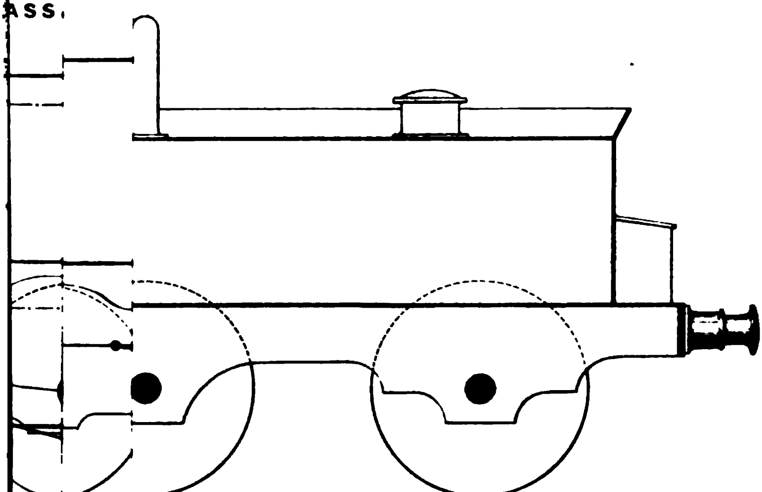


linder . . . 12 Tons 0 Cwts.
nmeter . . . 13 " 10 "
. . . 7 " 18 "
eel Bd Total: 33 " 8 "
al leng of Water . . . 27 Tons 7 Cwts.
ating s . . . 2250 Gallons.
e grat rking order . . . 60 Tons 15 Cwts.

THOs KELL & SON LITH. 40, KING ST COVENT GARDEN

PLATE. 9.

Fig: 8.

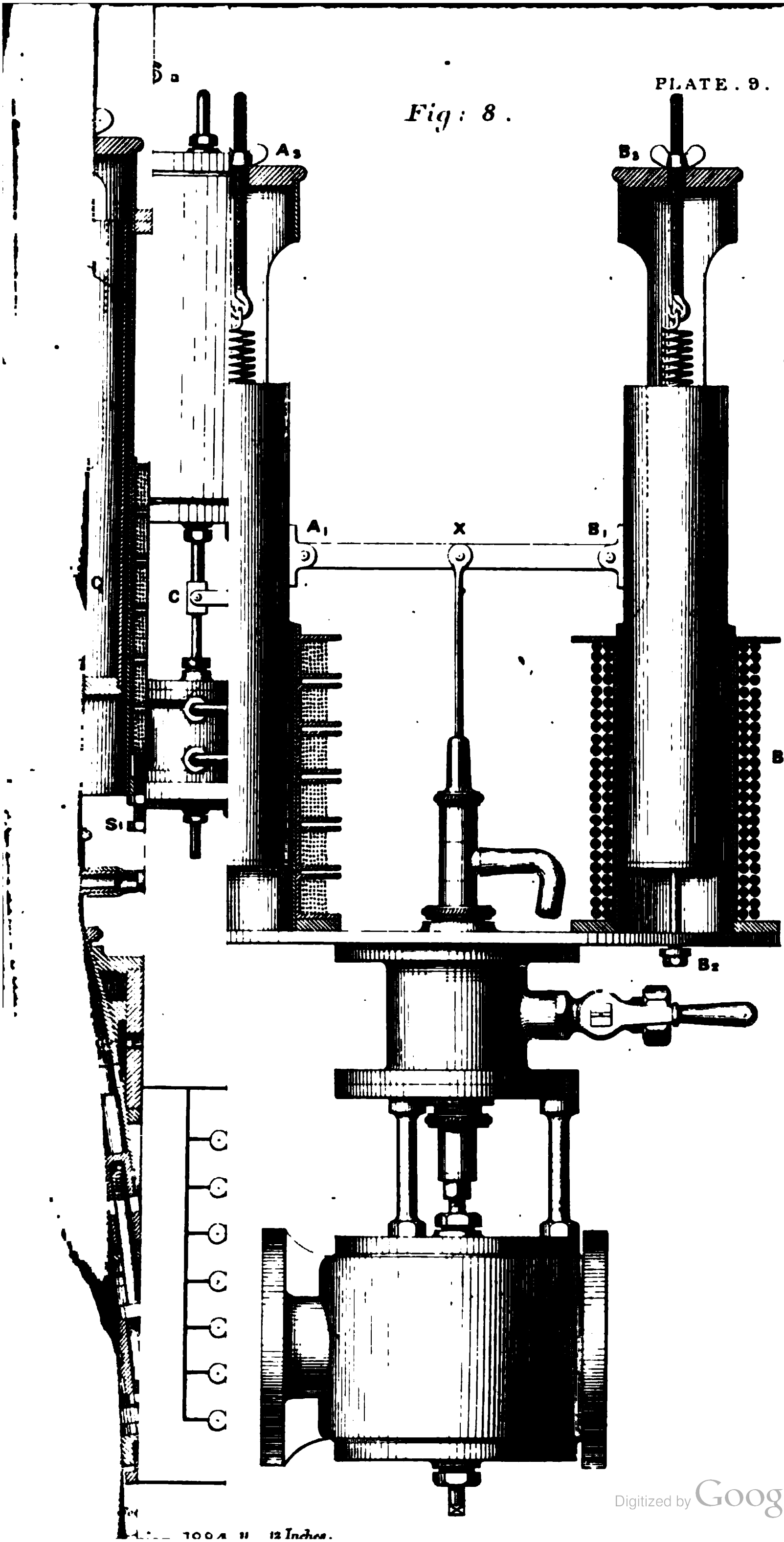
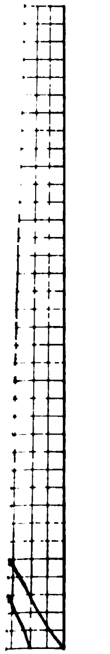
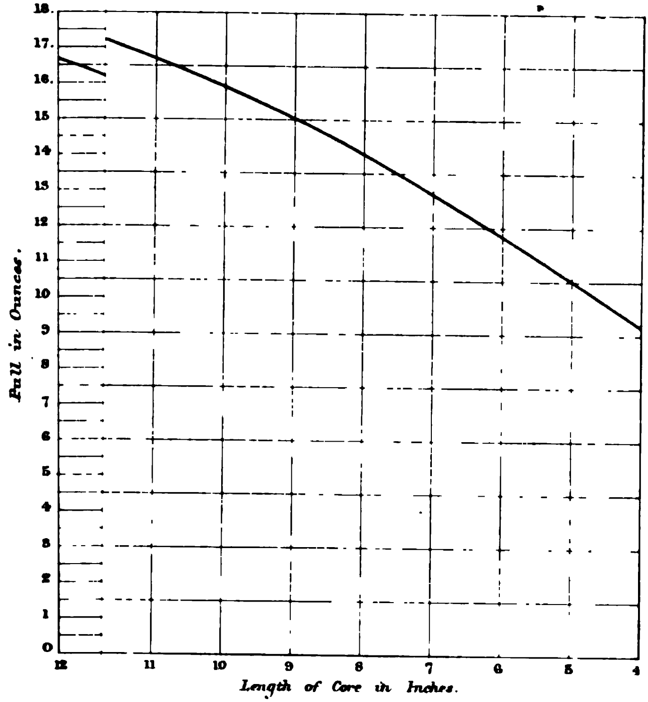


Fig: 12.

Curve of Percentage of Length of Core outside the winding at the point of Maximum Pull.





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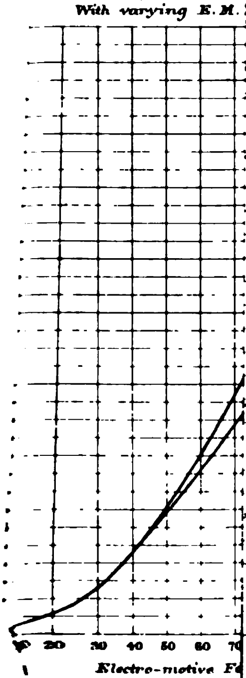


Fig: 15.

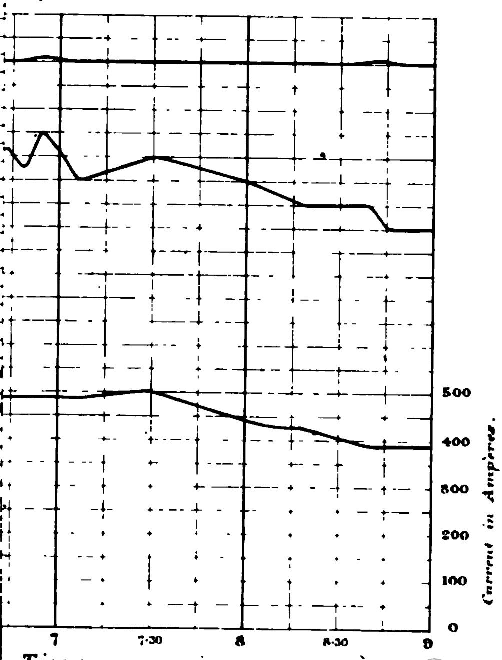
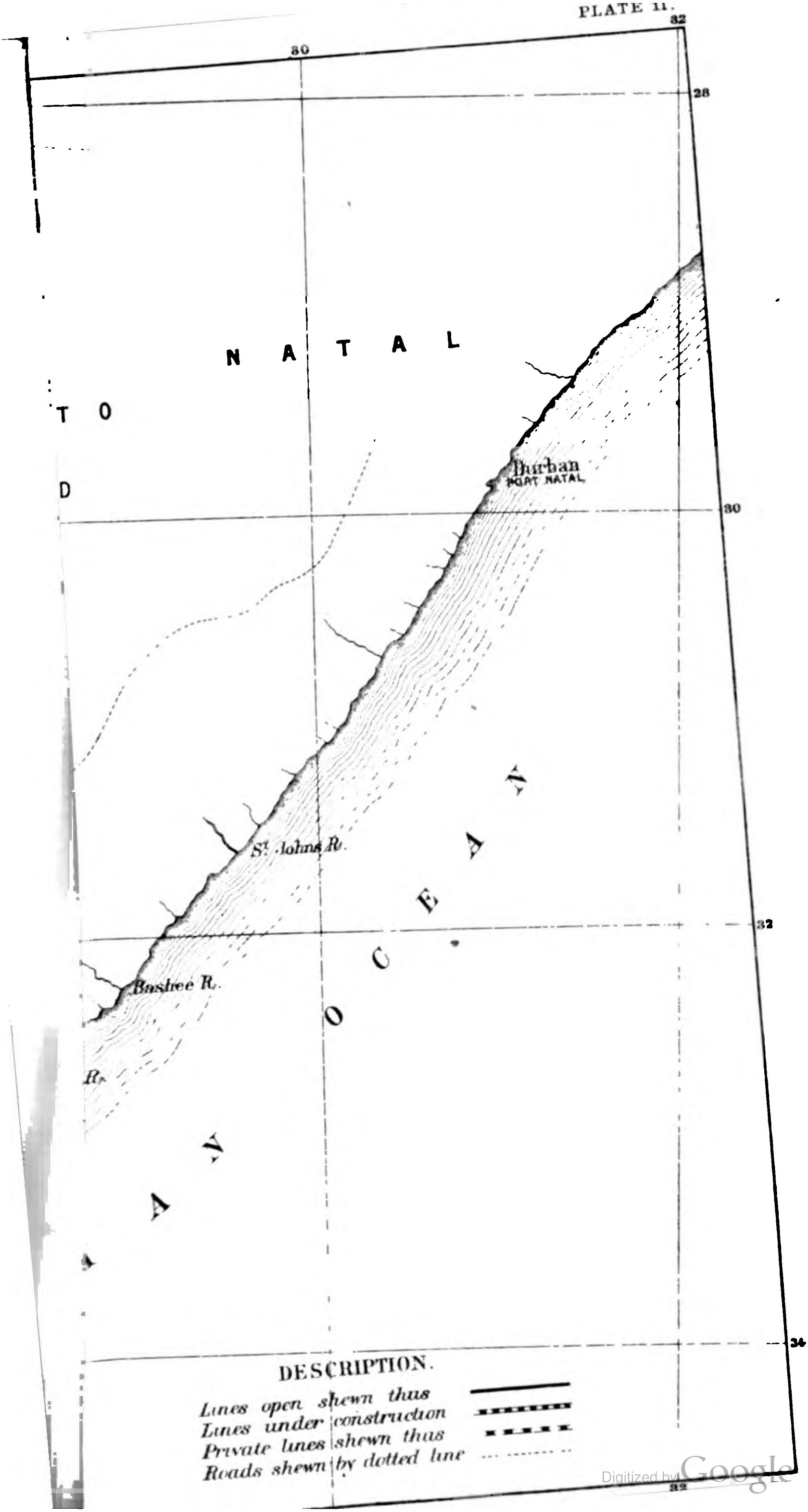


PLATE II.



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32
34
DESCRIPTION.
Lines open shewn thus
Lines under construction
Private lines shewn thus
Roads shewn by dotted line

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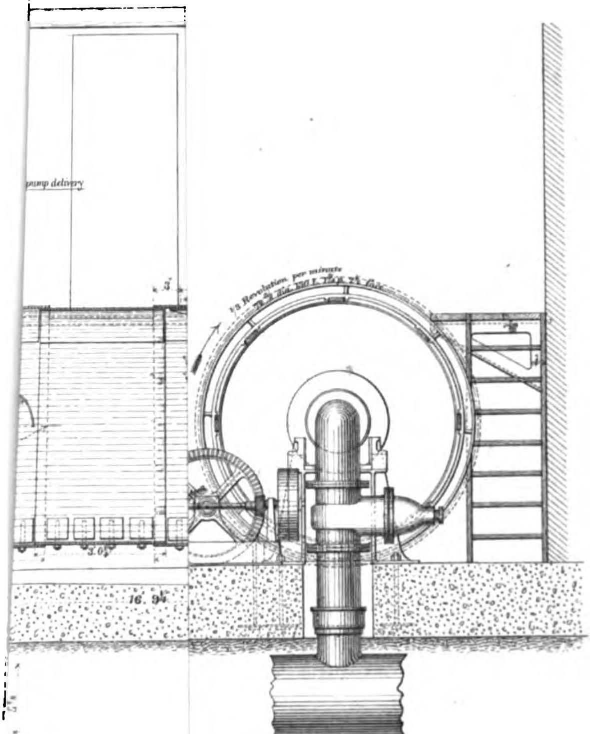
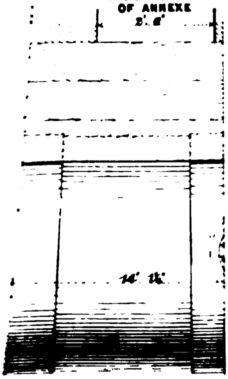
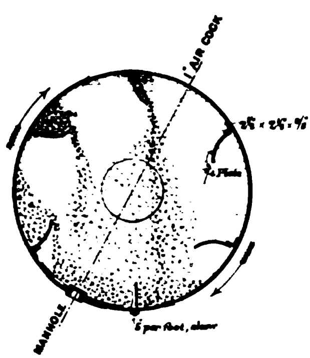
PLATE. 12.



DOOR IN CENTRE OF ANNEXE
2'. 6"





Ins. 12 9 6 3 0 1

THOS KELL & SON LITH 40 KING ST COVENT GARDEN

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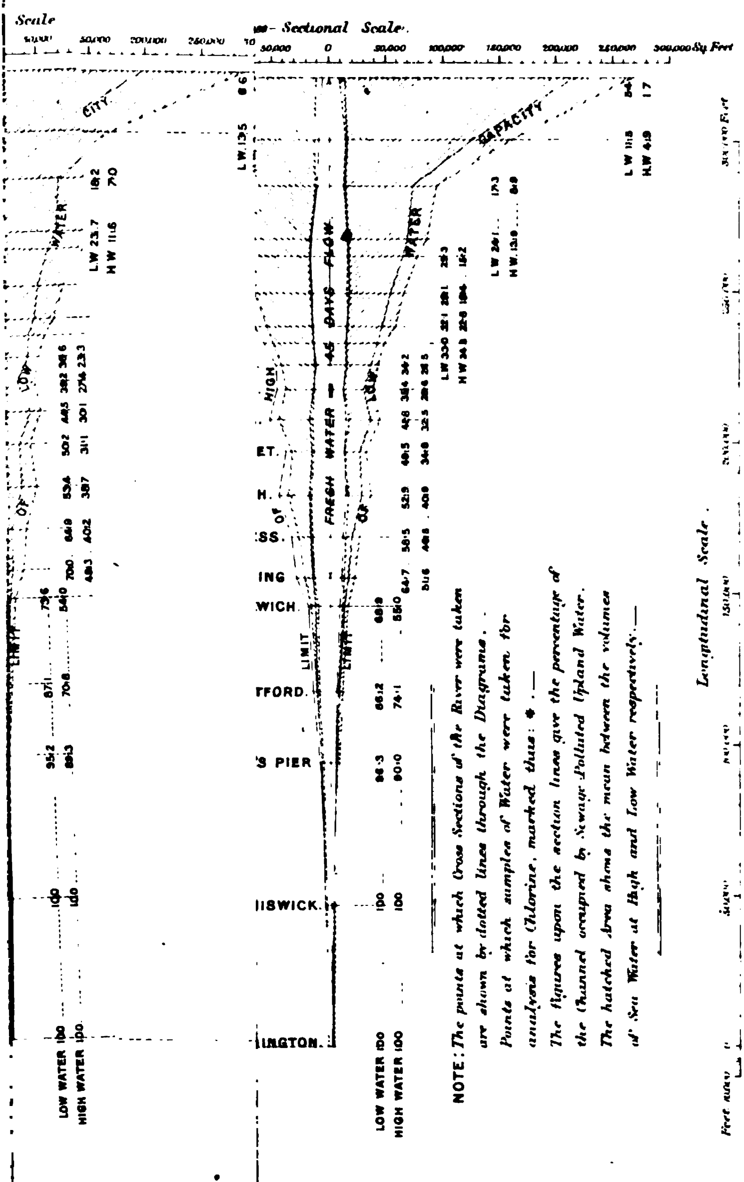
PLATE 13.



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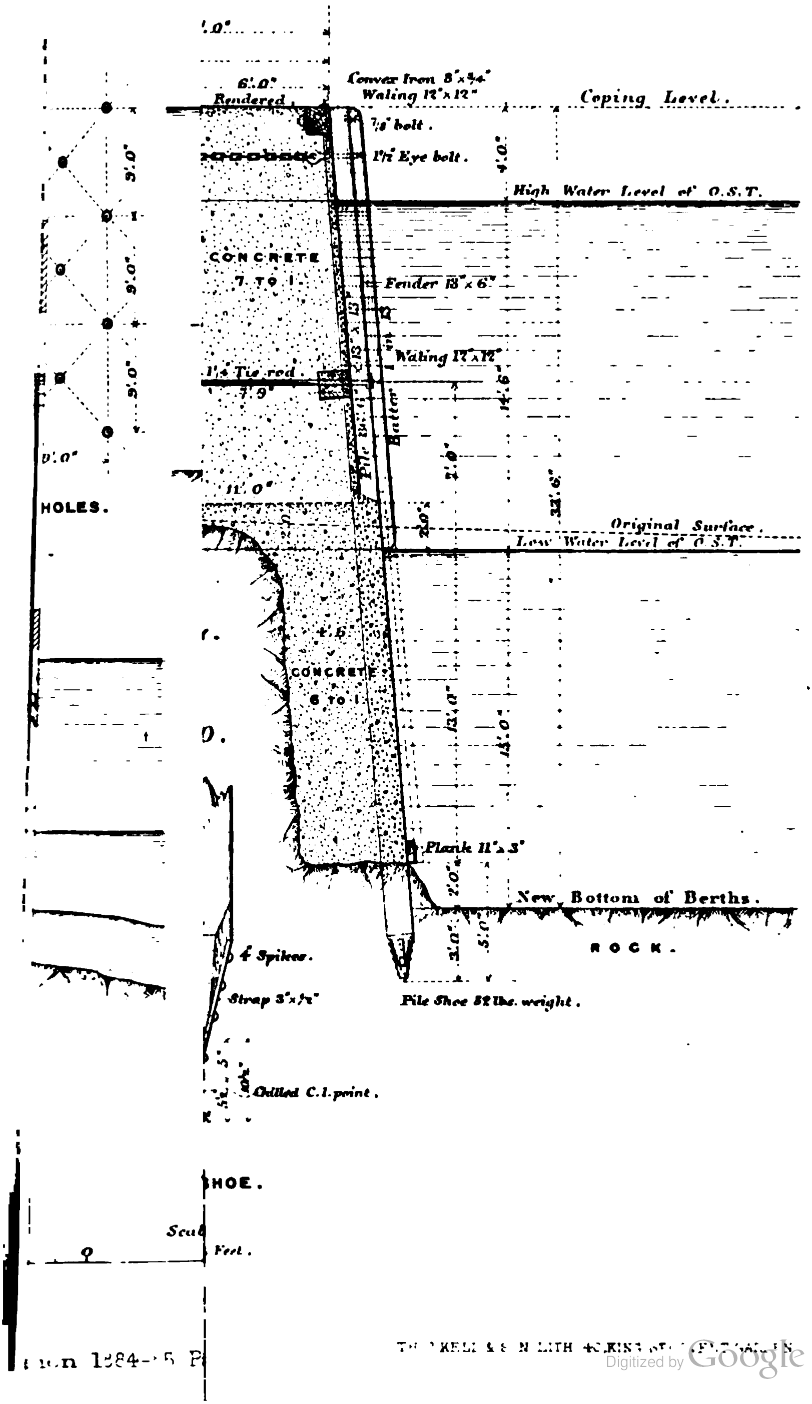
THOS KELL & SON LITH 40 KING ST COVENT GARDEN


Convex Iron 8"x3/4"
Waling 12"x12"
Rendered
Coping Level.
7/8" bolt.
1 1/2" Eye bolt.
High Water Level of O.S.T.
CONCRETE
7 TO 1
Fender 13"x6"
Waling 12"x12"
1 1/4 Tie rod.
HOLES.
Original Surface.
Low Water Level of O.S.T.
CONCRETE
6 TO 1
Plank 11"x3"
New Bottom of Berths.
ROCK.
4" Spikes.
Strap 3"x1/2"
Pile Shoe 82 lbs. weight.
Chilled C.I. point.
HOE.
Feet.